Process-based evaluation of LES and SCM simulations using in-situ observations and satellite retrievals

Implications for GCM cloud parameterizations

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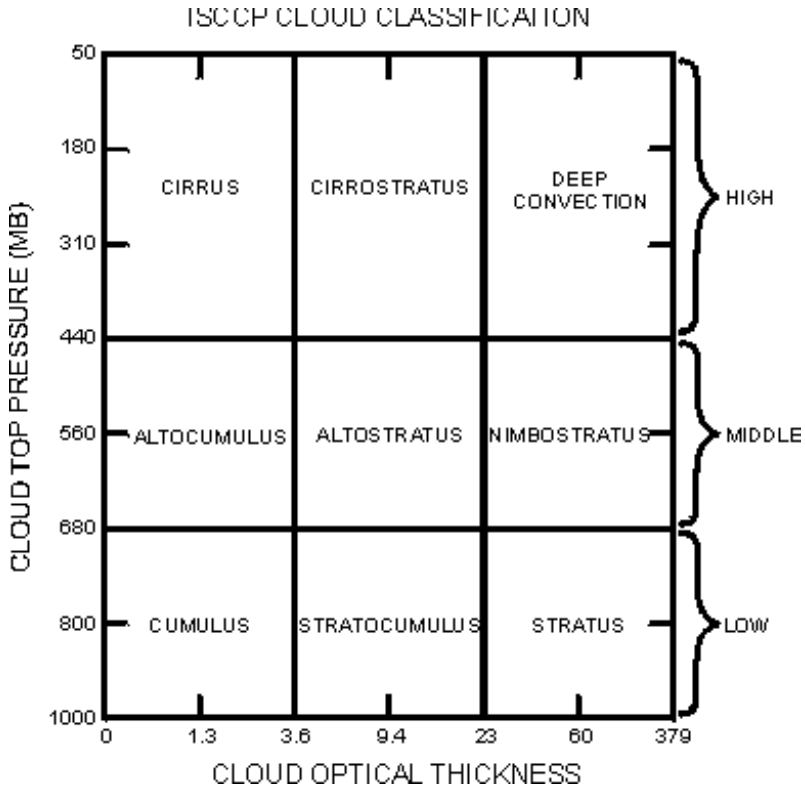
Outline

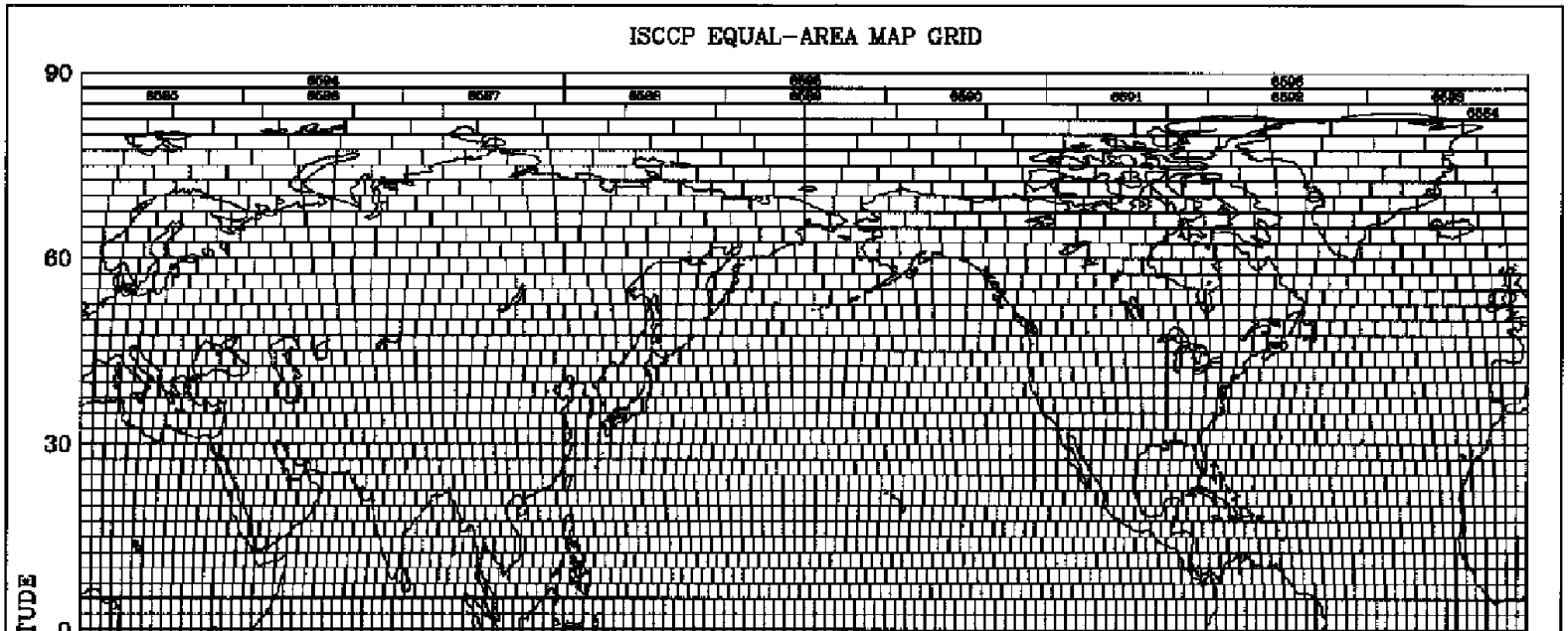
What is ISCCP?

- International Satellite Cloud Climatology Project
- Passive satellite measurements in the visible and infrared are used to detect and classify clouds globally.
- The results are available every 3 hours, from mid-1983 to 2009 (will be extended soon).



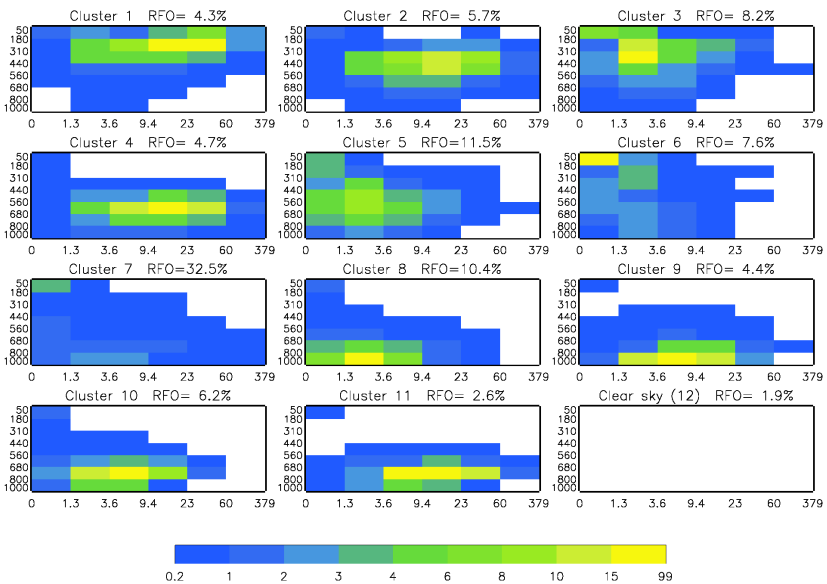
What are PC-Tau histograms?

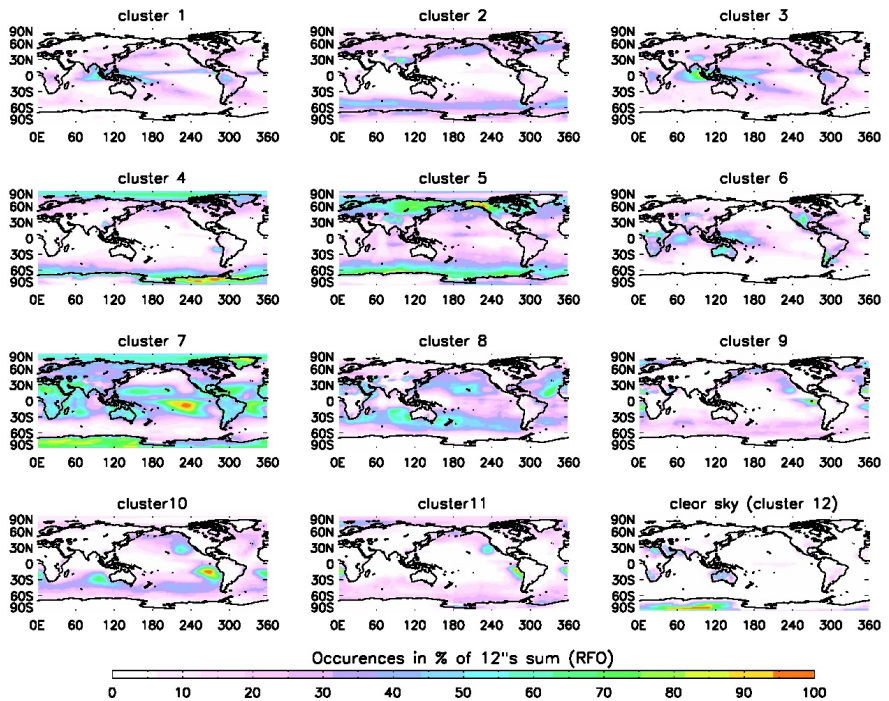
- Each pixel in a satellite picture accounts for 1 combination of cloud-top pressure (PC) and optical depth (Tau).
- Putting all pixels from a broader region together, they provide the fraction of horizontal space in that area characterized by each possible combination.
- Each histogram represent the situation in a grid cell that contains many observed pixels.
- For now, in the ISCCP observations, this is done on a 2.5x2.5 degrees equal area grid.



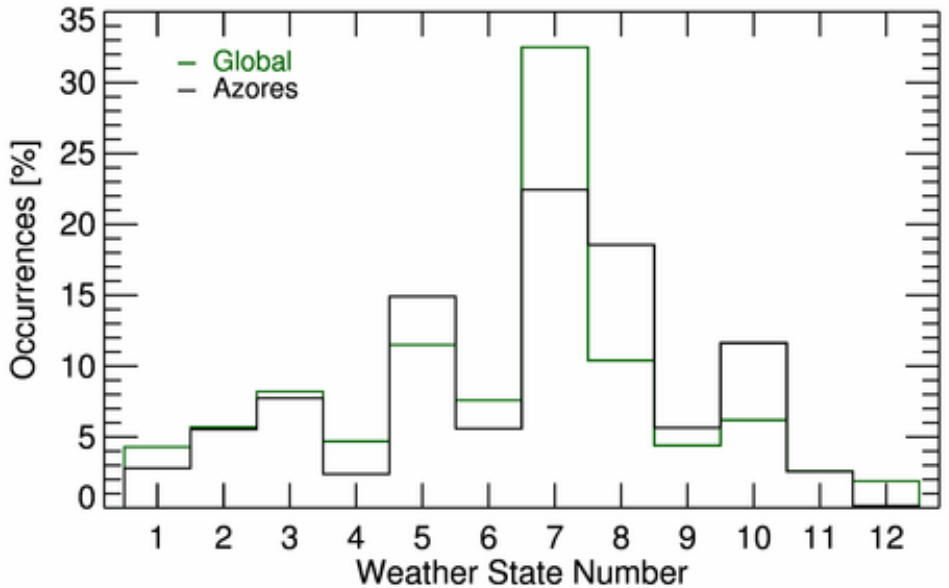
Clustering PC-Tau histograms

- Clustering is performed to analyze more easily these data, allowing the determination of the different types of weather present in the data set.
- Resulting clusters are often referred to as “weather states”, and each can be associated to specific cloud regimes:
  - Separation of tropical and midlatitude convective clouds
  - Tropical–subtropical region shows a stratocumulus–shallow cumulus–fair weather balance





WS occurrences



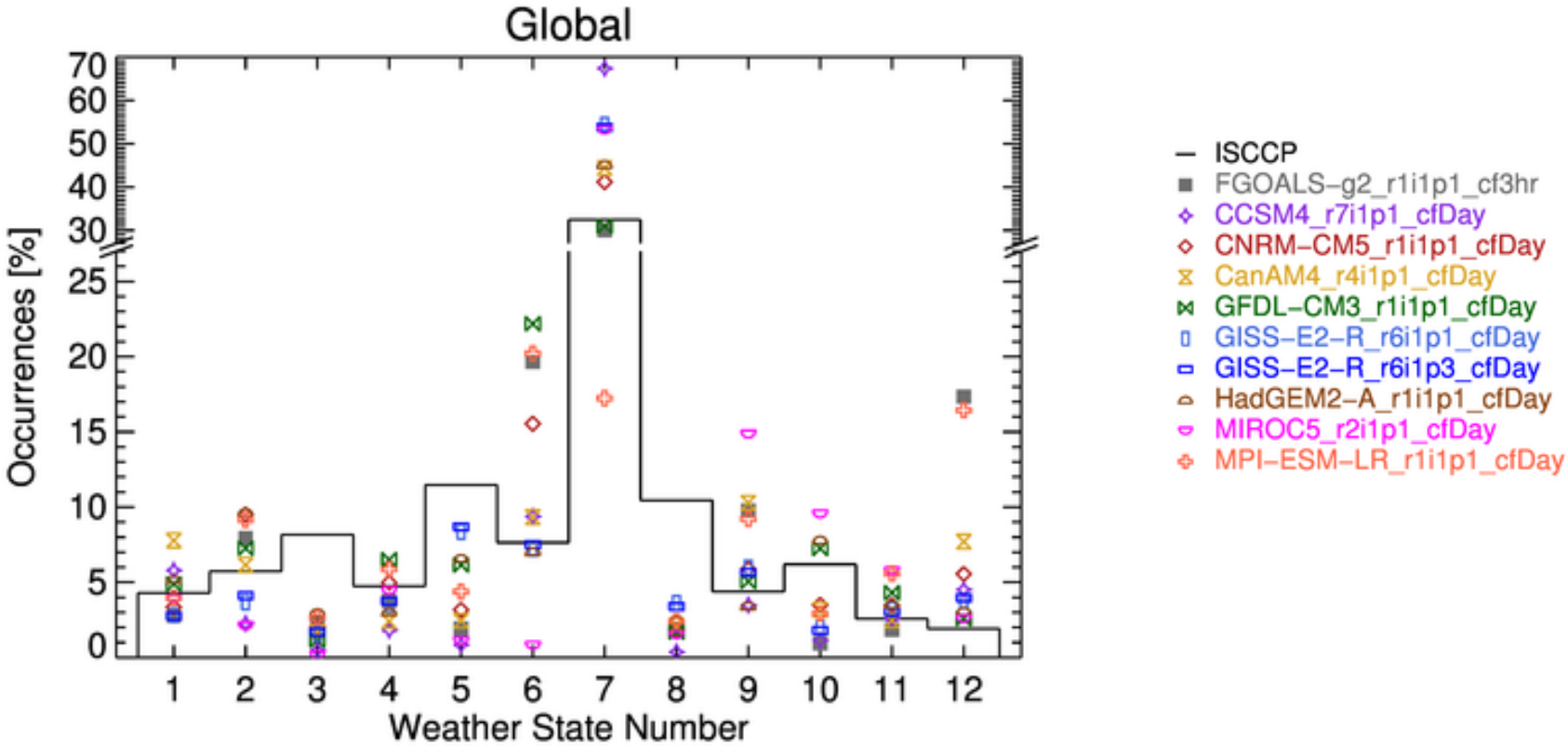
- Fair weather scenes (WS7) dominates the picture;
- Shallow cumulus (WS8) and mid-level (WS4–5) scenes follow.
- Stratocumulus (WS9–11) and convection (WS1–3) clouds similarly represented overall;

Outline

Global models and CMIP5

- Coupled Modeling Intercomparison Project Phase 5
- "Meant to provide a framework for coordinated climate change experiments".
  - Requests the inclusion of diagnostic variables from a satellite simulator (e.g., PC-Tau histograms similar to the ISCCP ones).
  - This output should be for a model run covering at least 30 years, from 1979 to 2008.

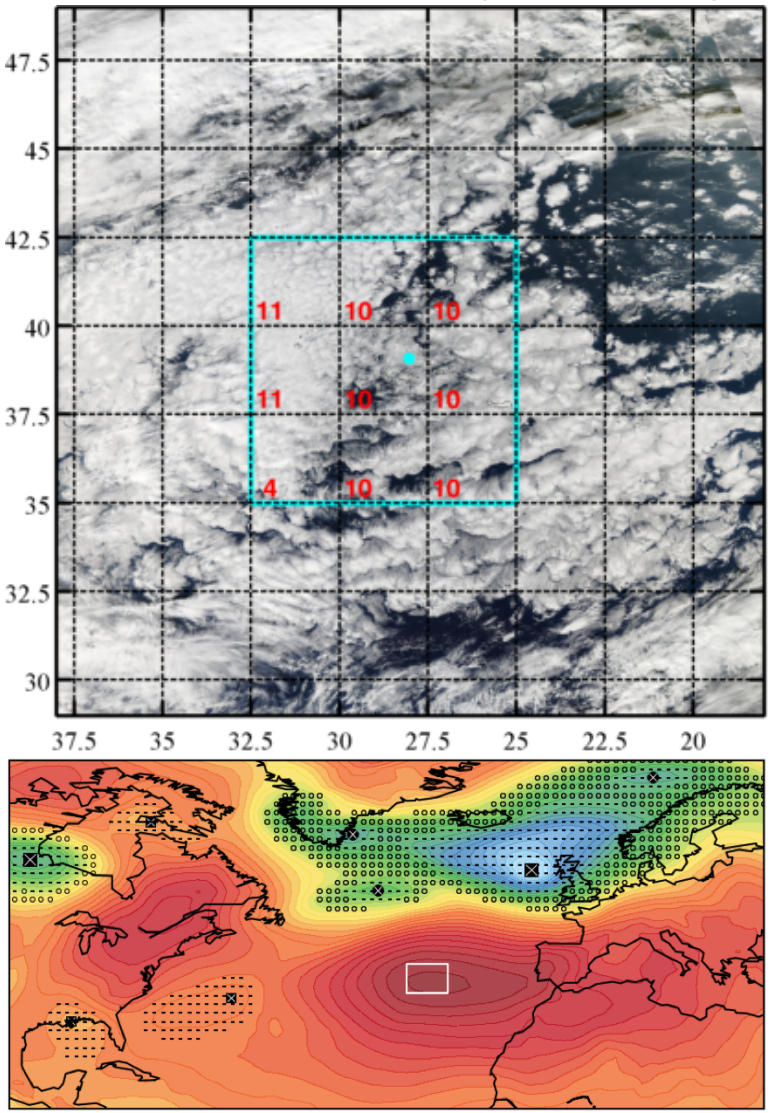
Weather States in CMIP5 GCMs



- WS7 (fair weather) is usually the most common, but most models overestimate its global occurrence.
- WS6 (thin cirrus) is also overestimated, as are the fully clear skies.
- WS3, WS5 and WS8 (thick cirrus, storm clouds, shallow cumulus) are underestimated.

Selection of cases

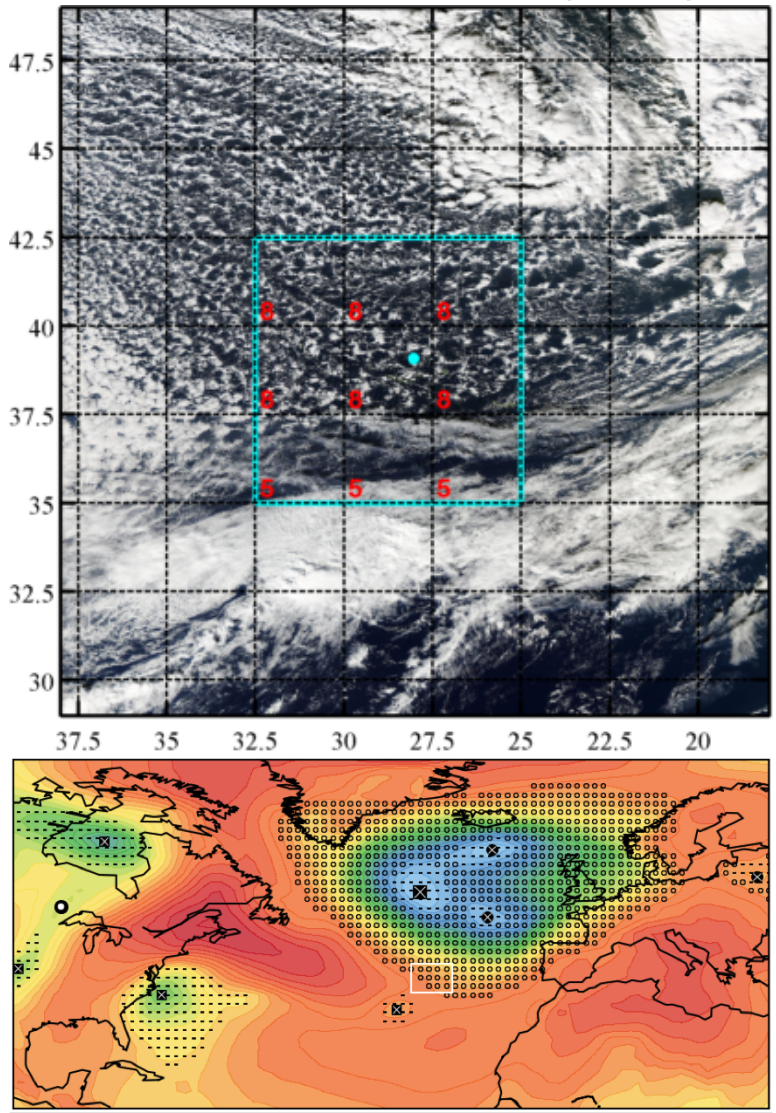
Stratocumulus case (WS10–11)



MODIS true-color imagery – 20x20 deg from Aqua platform

MCMS analysis of ERA-Interim sea-level pressure

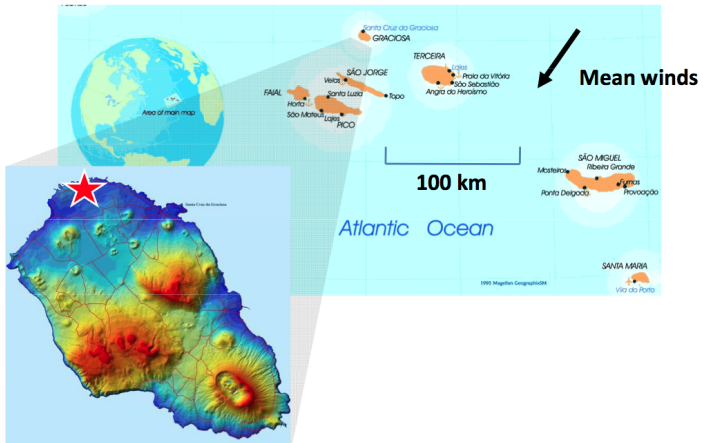
Shallow cumulus case (WS8)

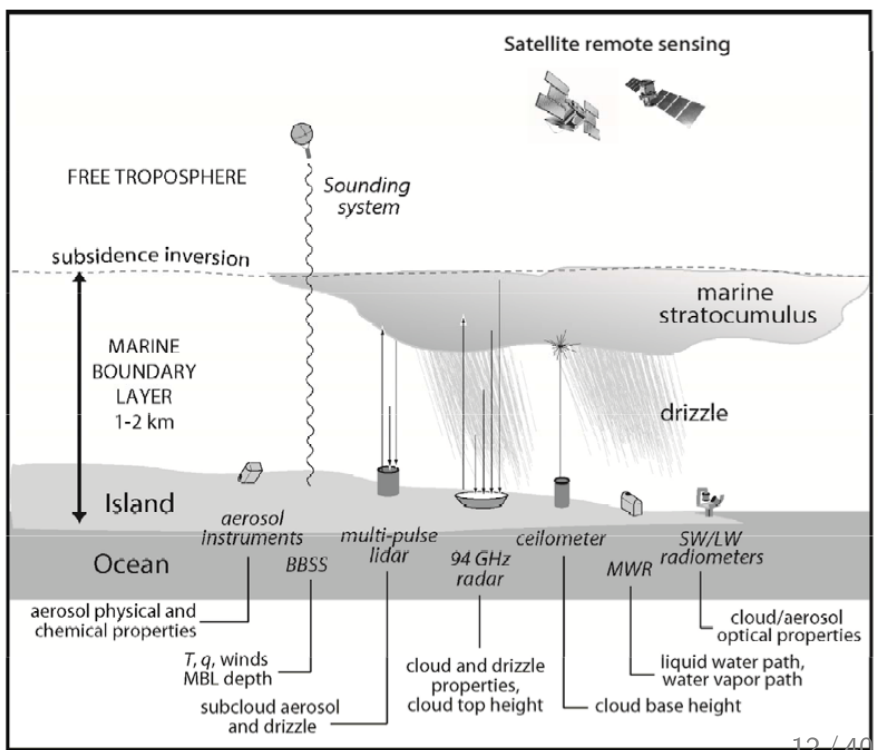


Outline

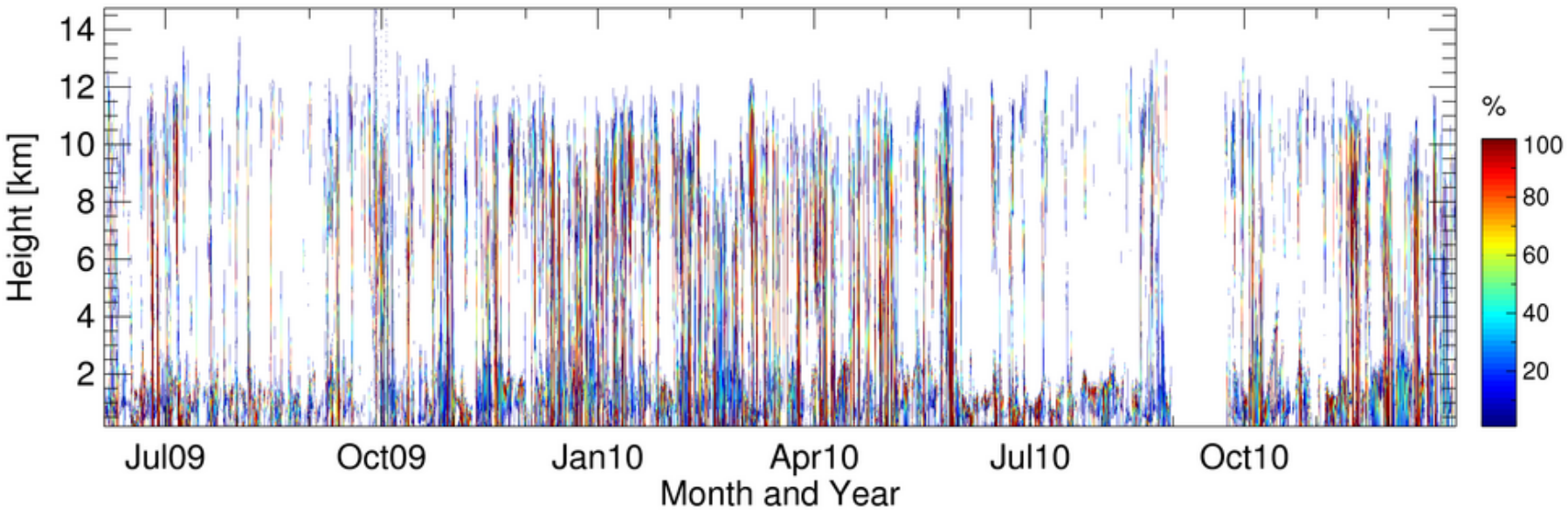
Why focus on the Azores region?

- 9 islands scattered in the middle of the North Atlantic, on the northern edge of the Azores high.
- A field campaign named Clouds, Aerosol, and Precipitation in the Marine Boundary Layer (CAP-MBL) took place in that region from May 2009 through December 2010.
- Various instruments were deployed with the goal of studying "processes controlling the radiative properties and microphysics of marine boundary layer clouds":
  - cloud radar, lidars
  - radiometers
  - sounding system, aerosol observing system





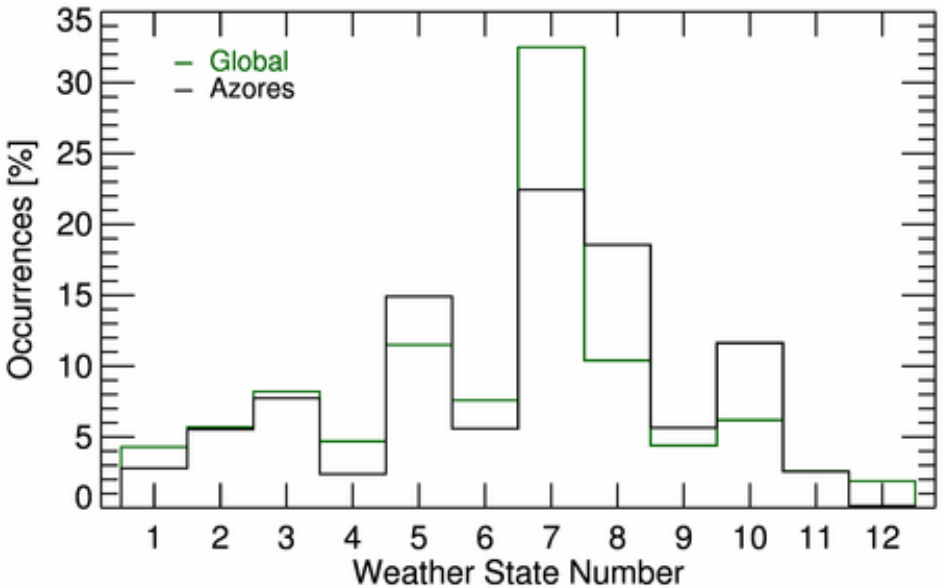
19-month curtain view



Range of cloud types observed:

- deep convection $\rightarrow$ in wintertime
- boundary layer clouds $\rightarrow$ all year long
- high clouds $\rightarrow$ their tops highlight the tropopause height

WS occurrences

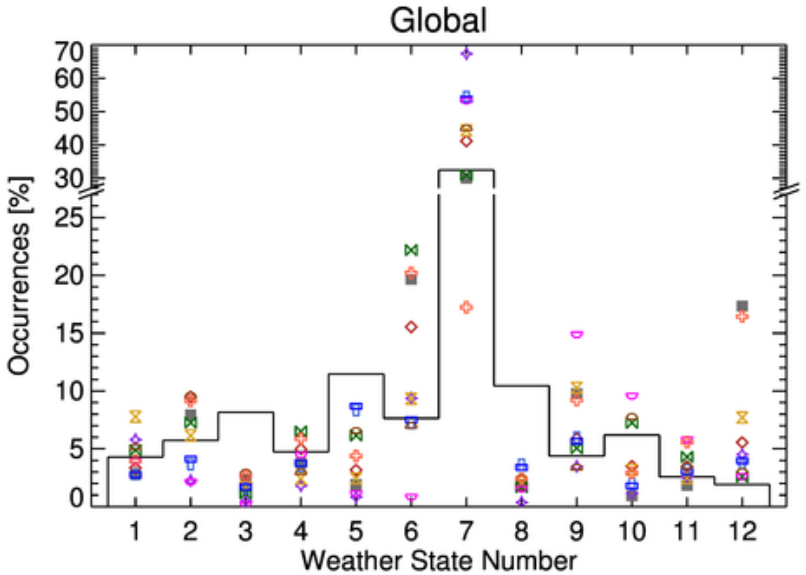


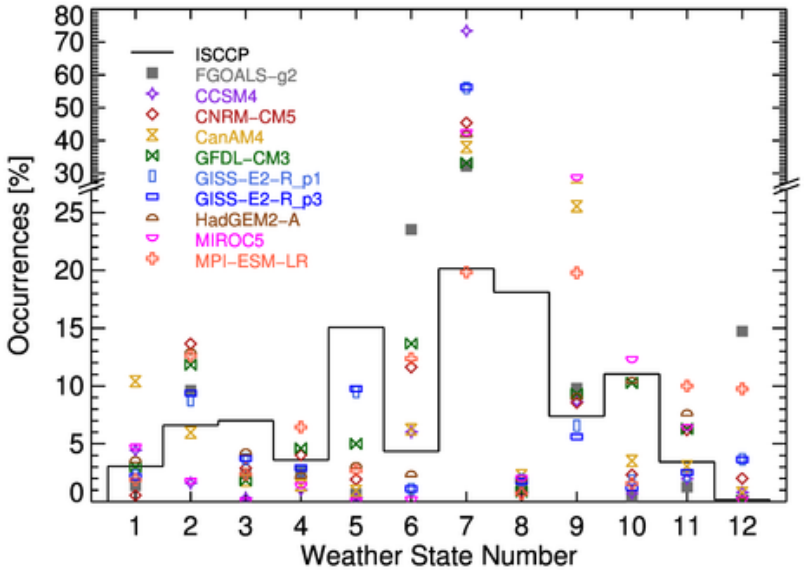
green = Global composite
black = Azores grid cell

The Azores area experienced:

- more low clouds (WS8–11) than the global average;
- less fair weather (WS6, 7 and 12) than the global average;
- about as much storm systems as the global average (WS2 and 5).

CMIP5 GCMs performance in the Azores

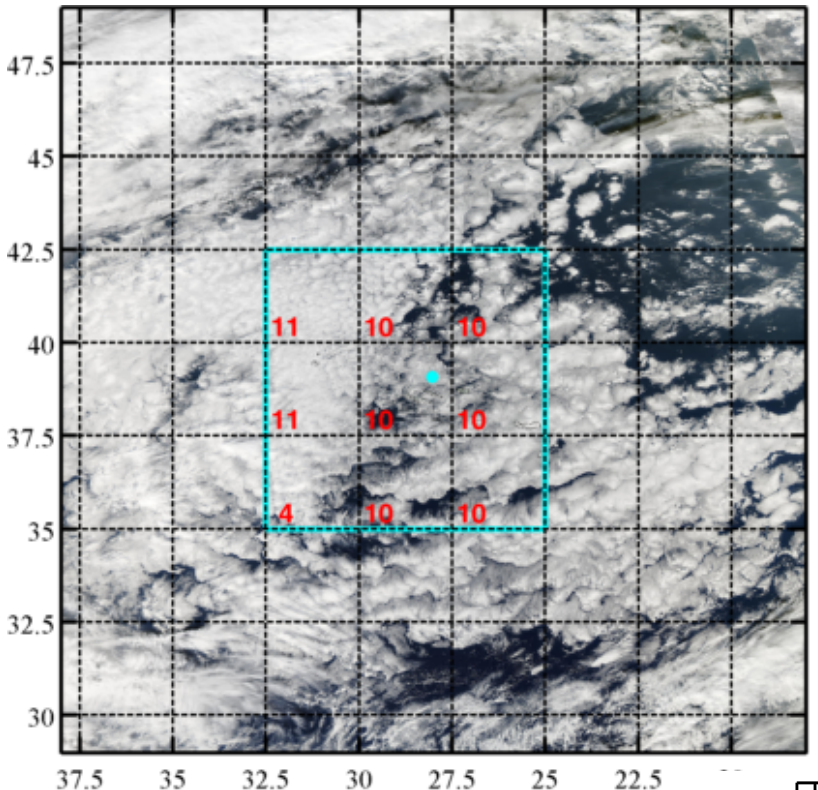


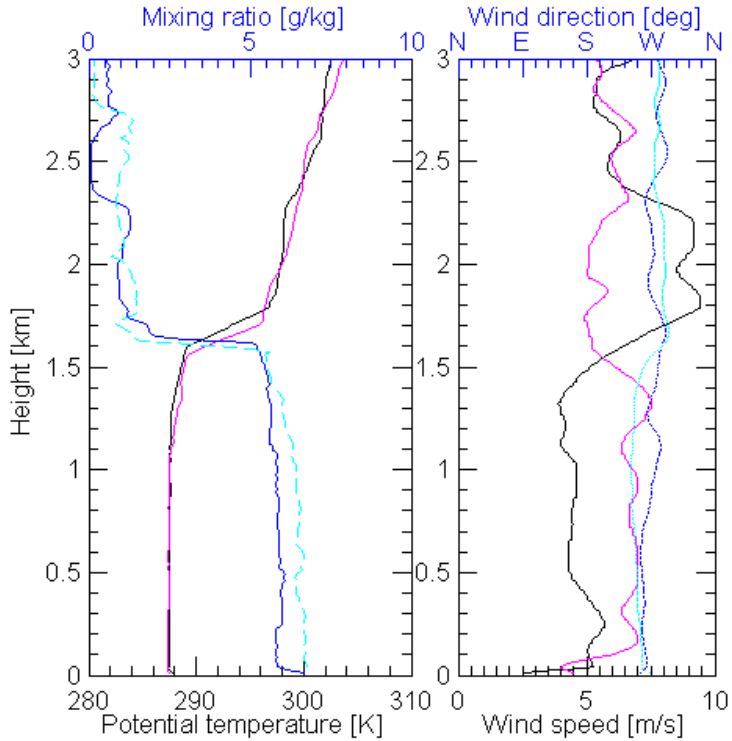


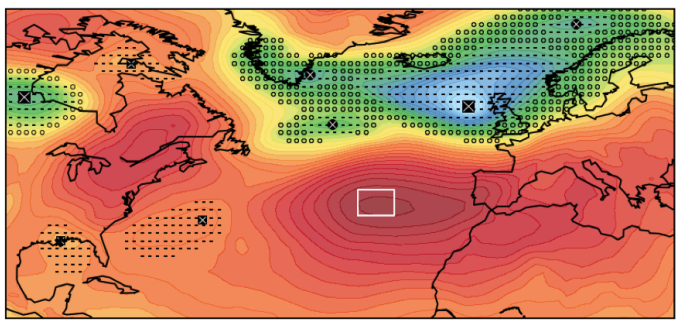
Most GCM WS deficiencies in the global domain are also present in the Azores analysis, even emphasizing some of them (e.g., WS7 and WS8).

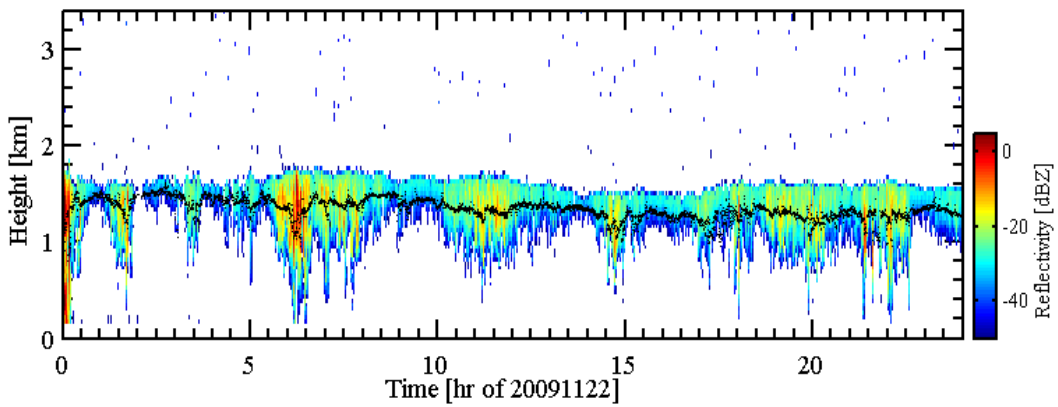
Outline

Observations

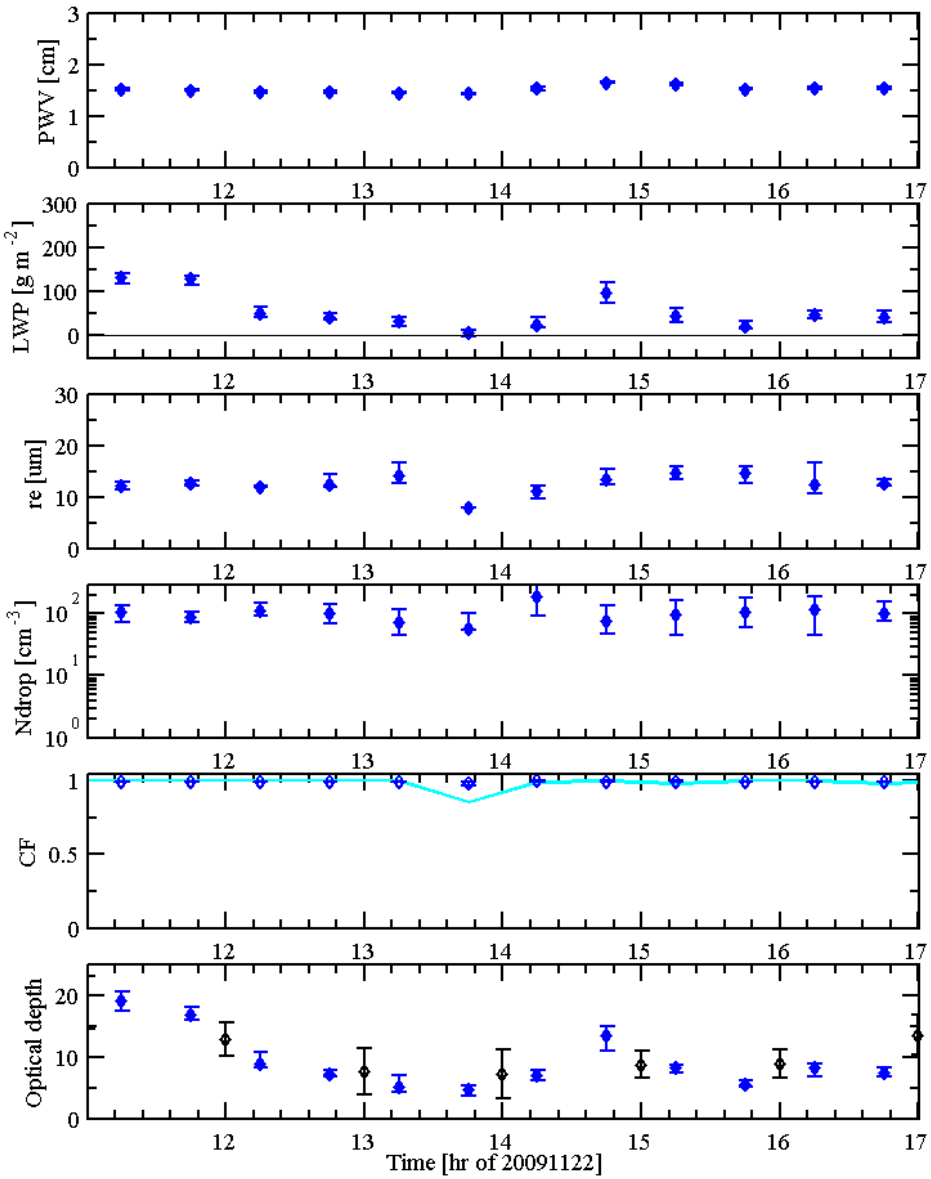


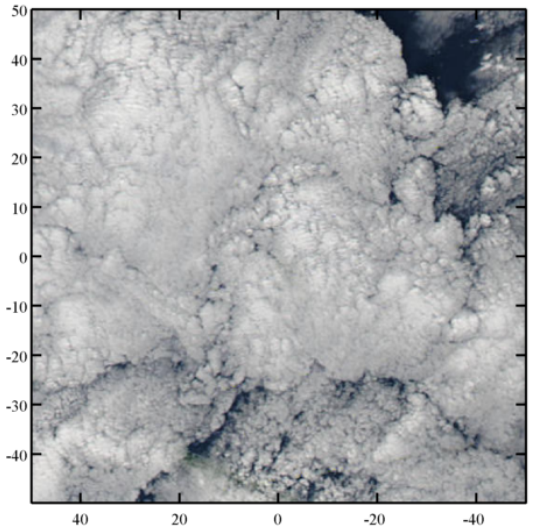


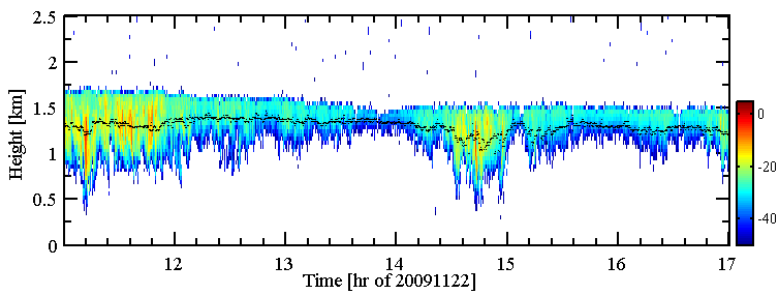




Focus period

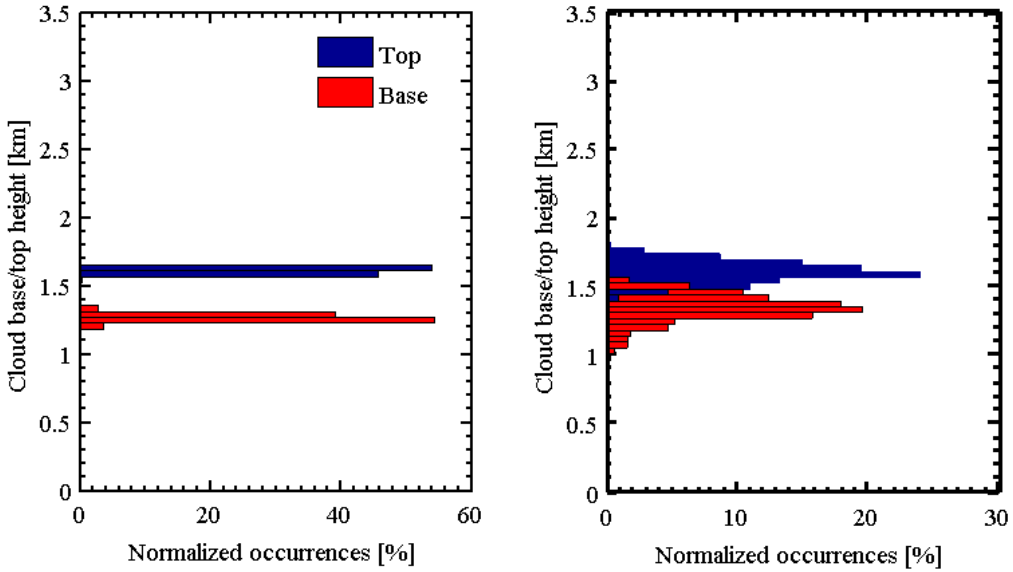






Large-Eddy Simulations – DHARMA

- 10x10 km domain, with periodic boundaries, and 100 m resolution
- extends to z = 2.5 km, with a 10–50 m resolution
- initial conditions from the idealized 1130Z sounding
- CCN = 260 cm^{-3}
- bin microphysics, with 25 mass-doubling bins



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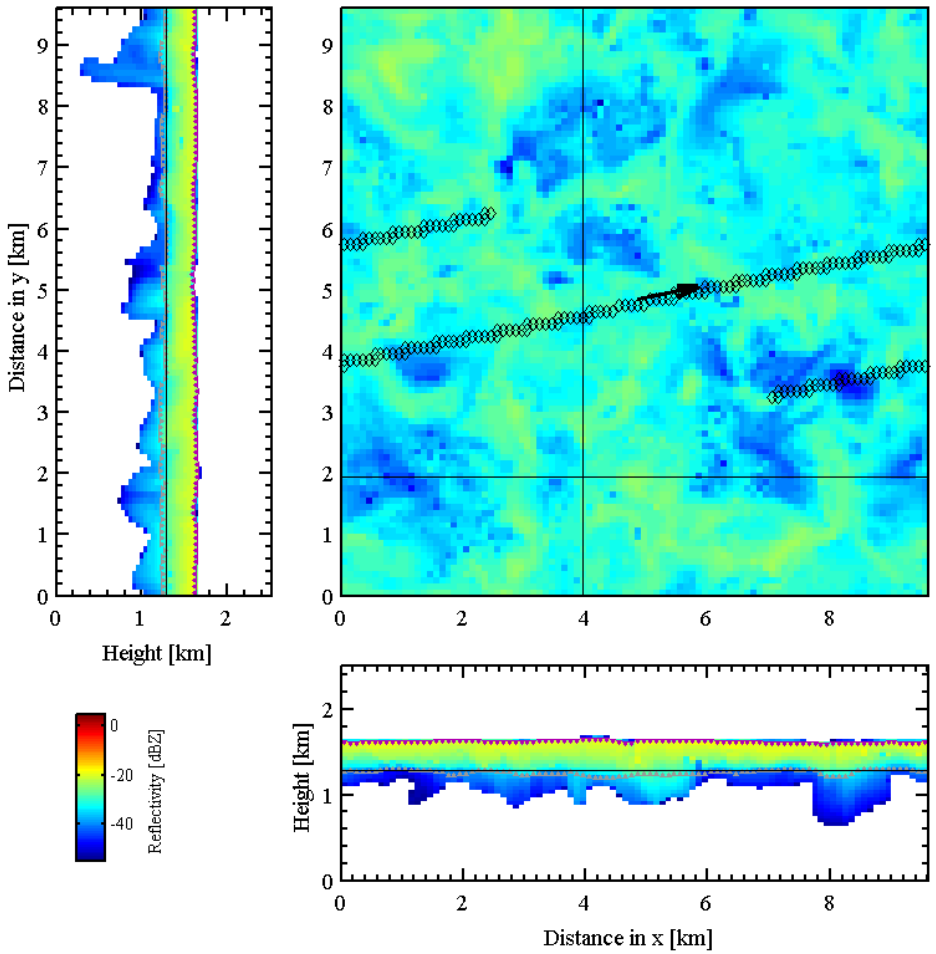
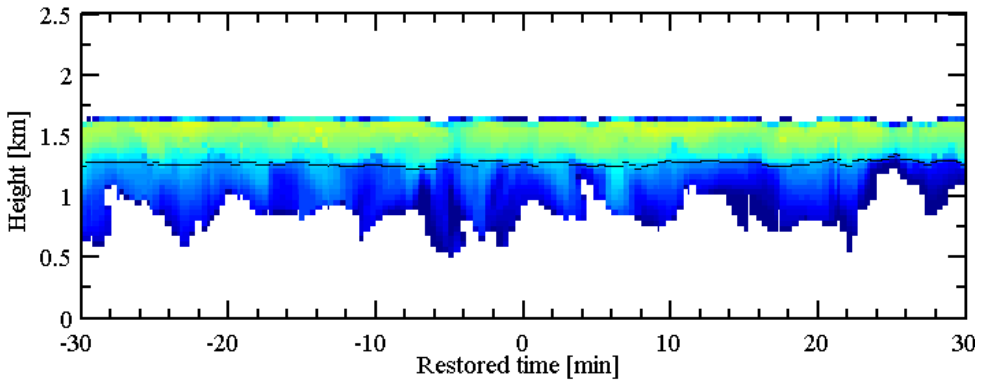
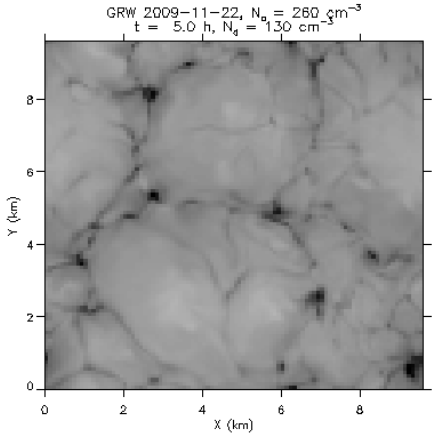


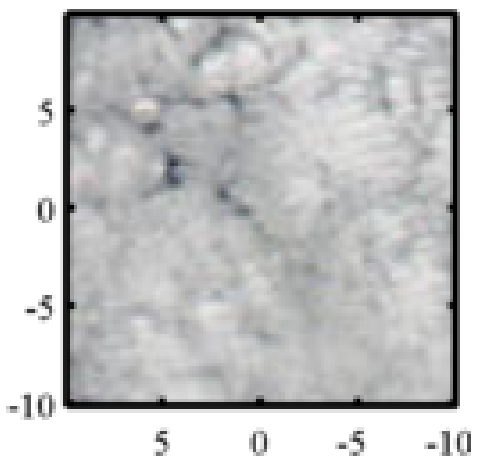


More LES results

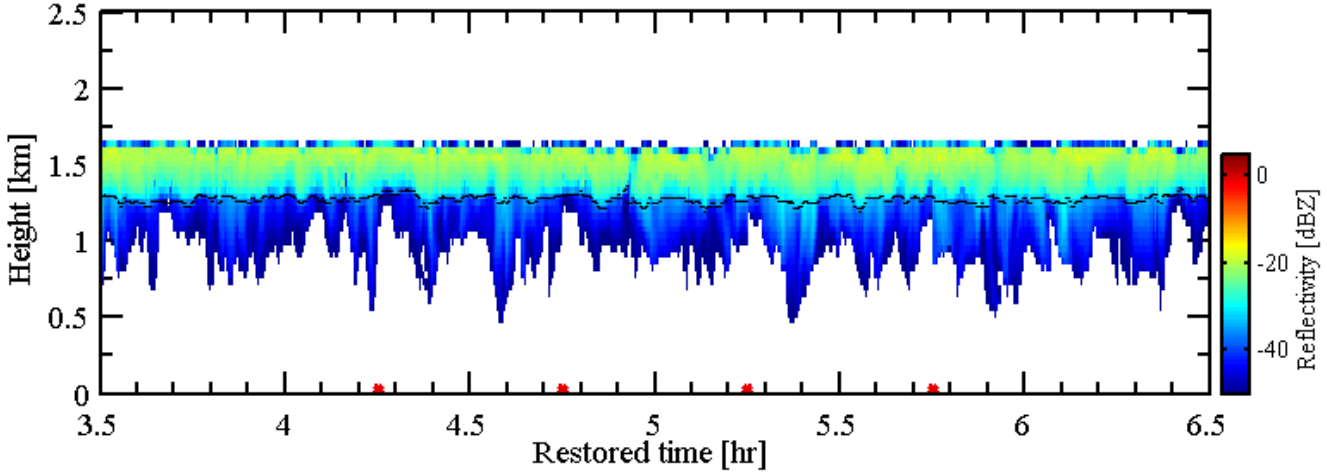
Pseudo-albedo



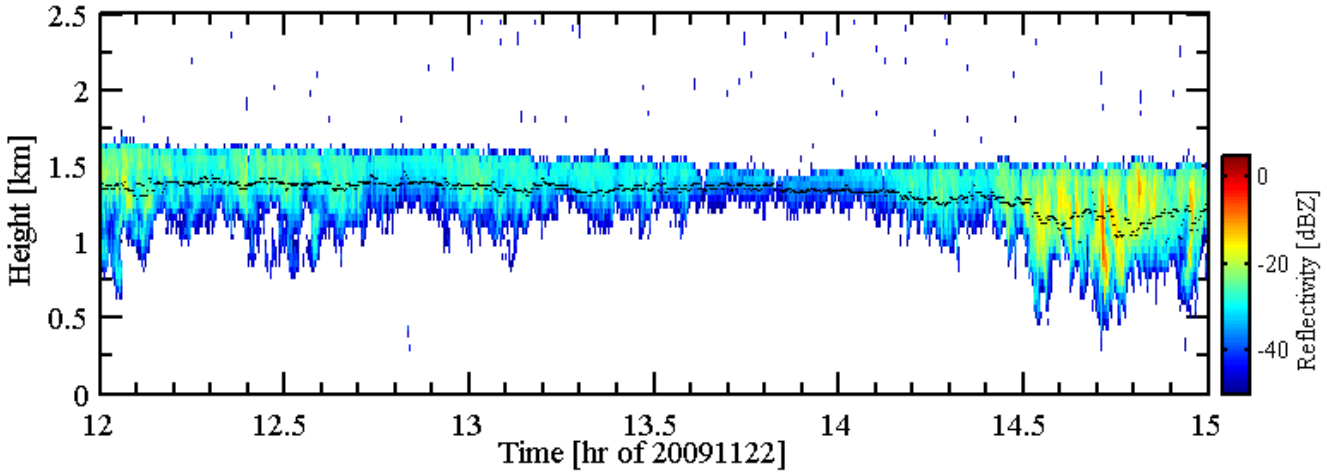
MODIS – 20km



3-hr stitched reflectivity curtain

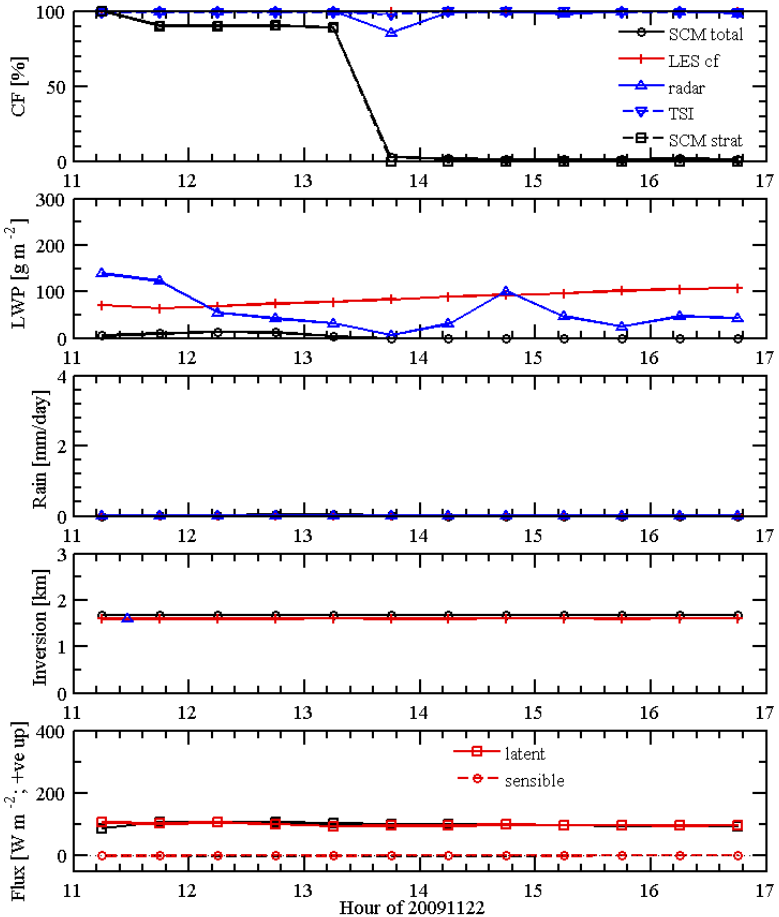


3-hr cloud radar reflectivity curtain

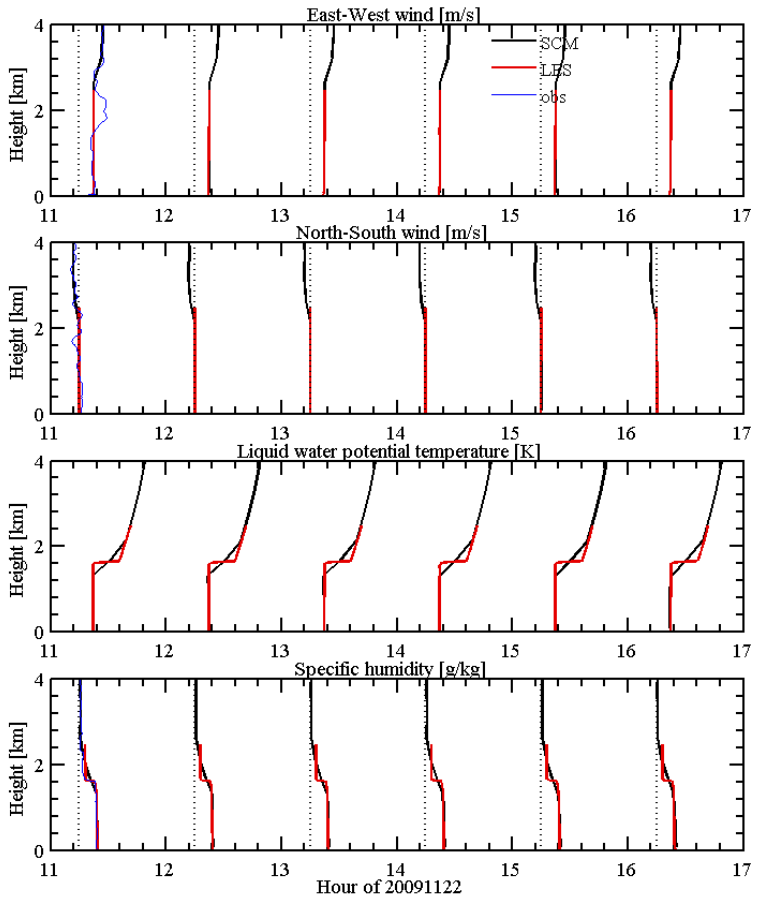


Single Column Model

Scalars

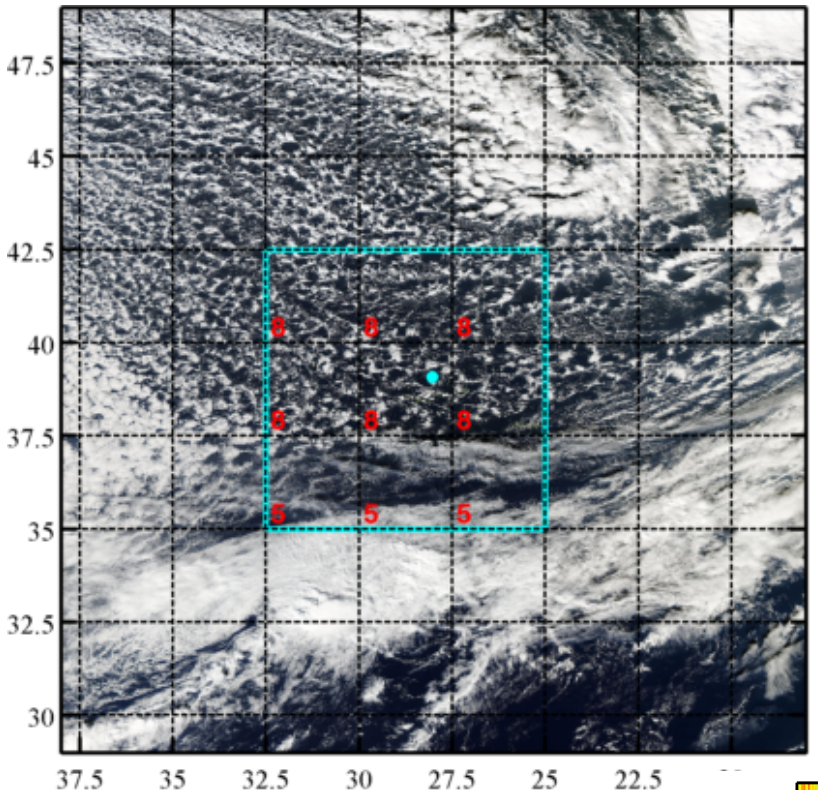


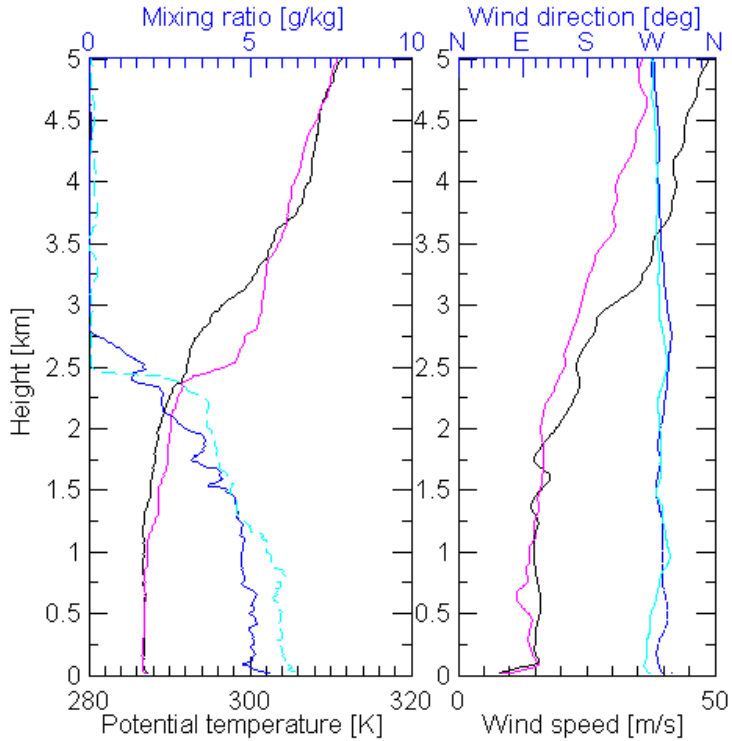
Soundings

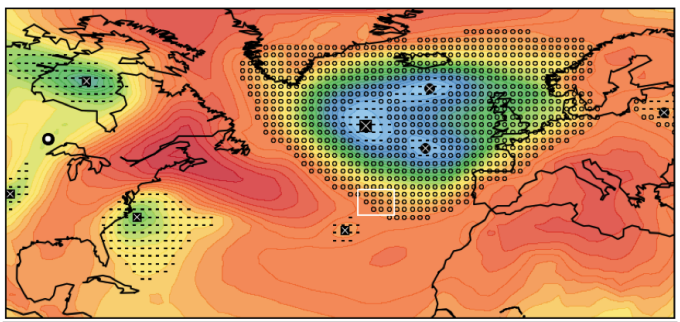


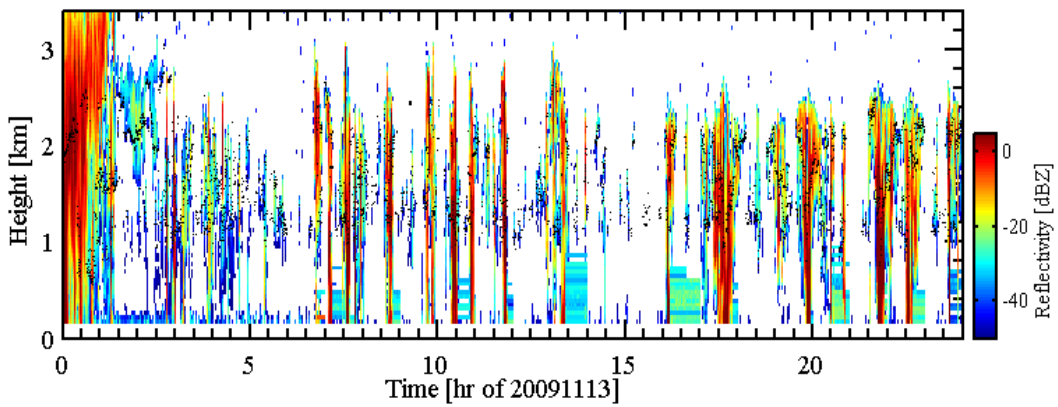
Outline

Observations









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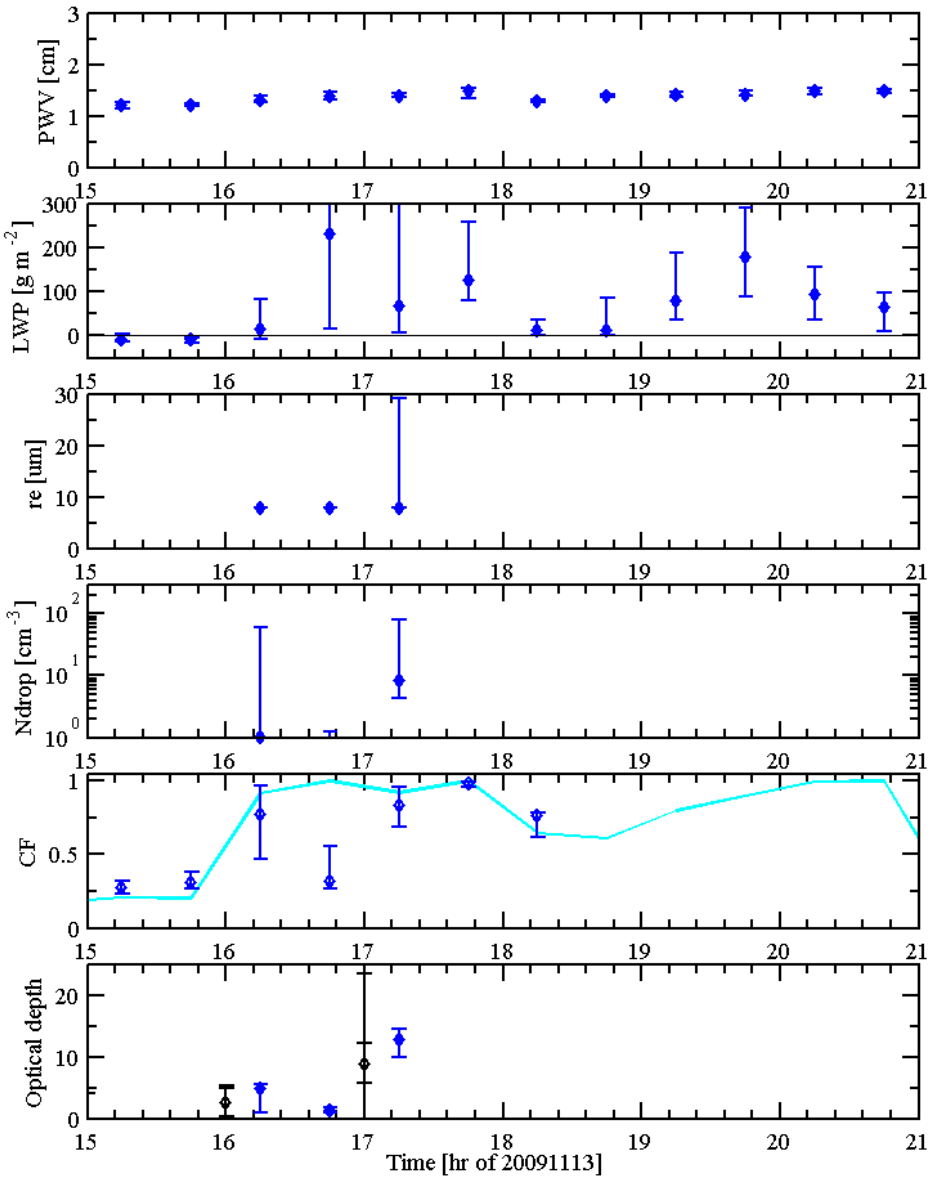
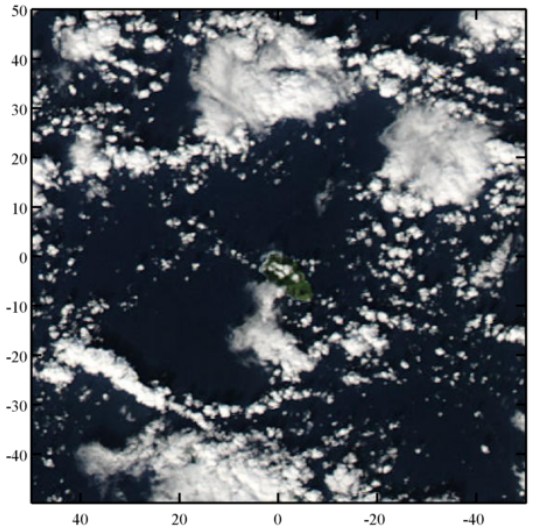
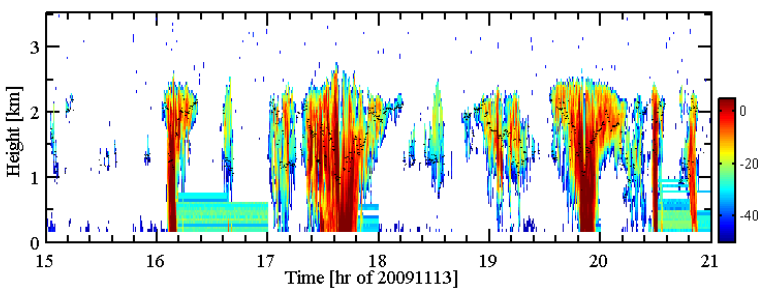
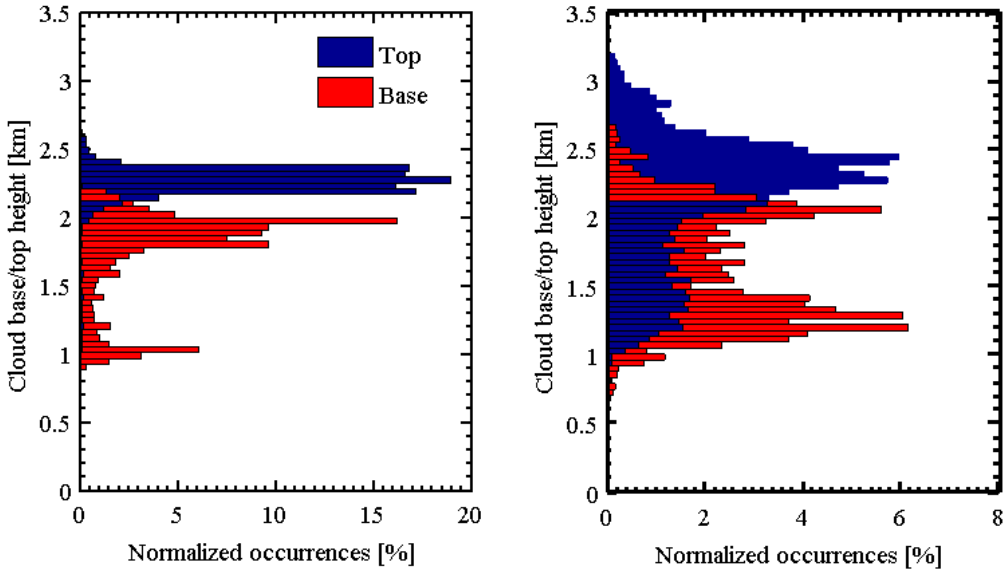






Large-Eddy Simulations – DHARMA

- 10x10 km domain, with periodic boundaries, and 100 m resolution
- extends to z = 3.5 km, with a 35 m resolution
- initial conditions from the 1730Z sounding
- CCN = 100 cm^{-3}
- bin microphysics, with 25 mass-doubling bins



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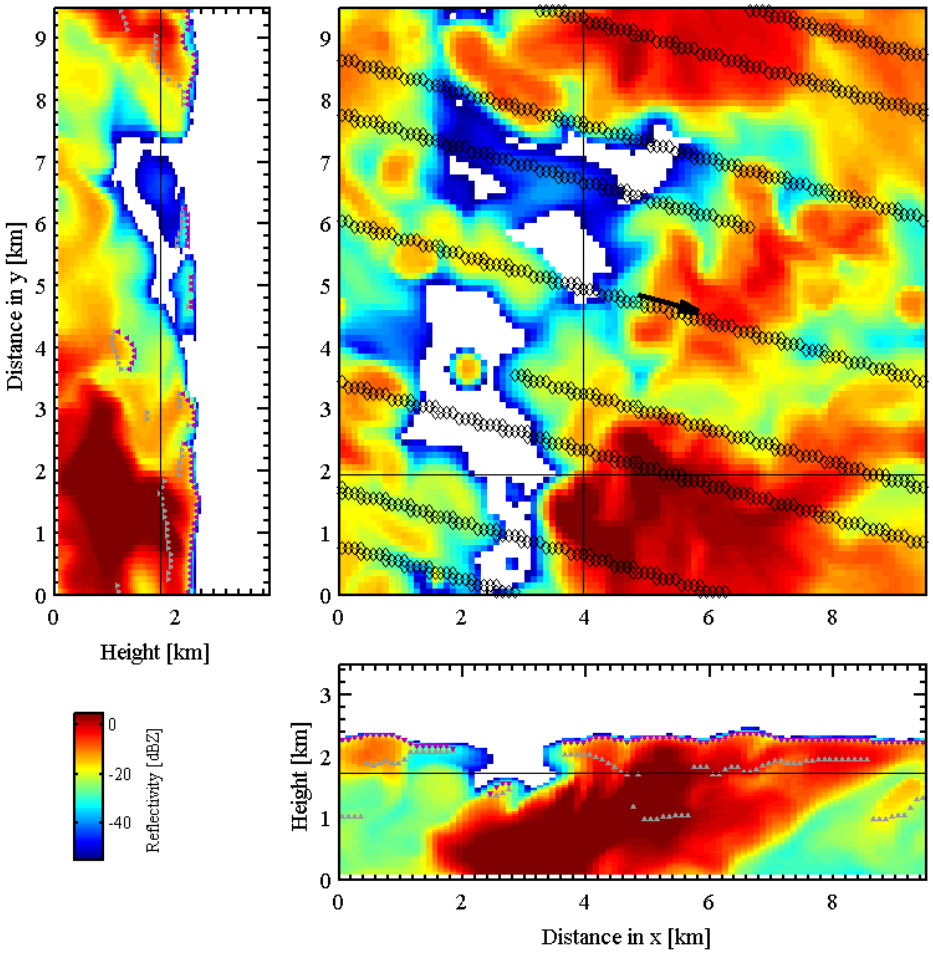

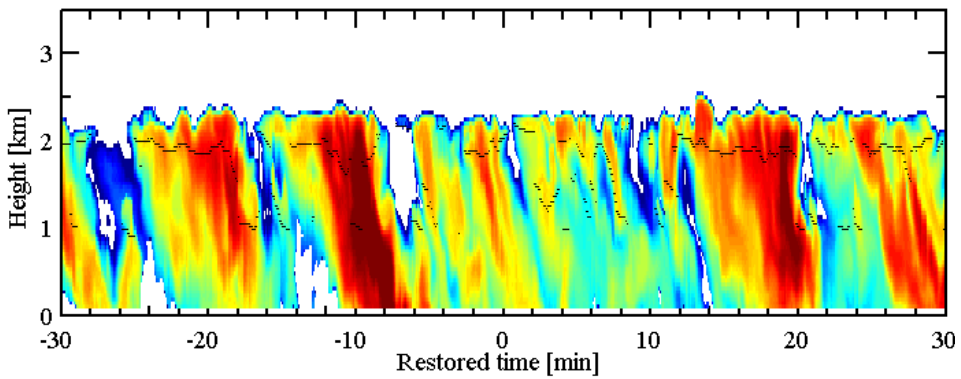

More LES results

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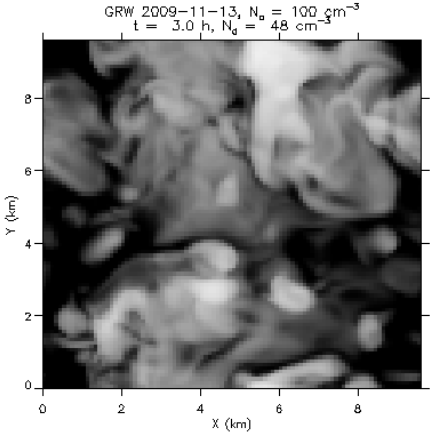
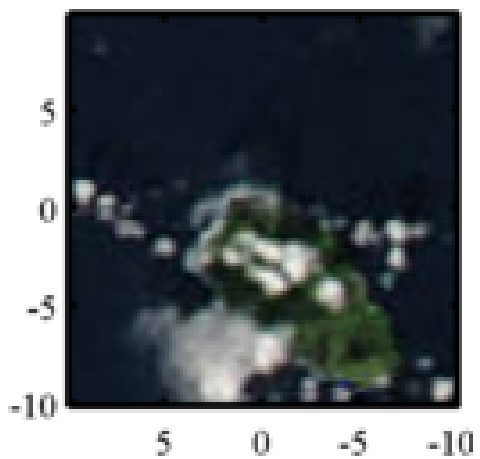
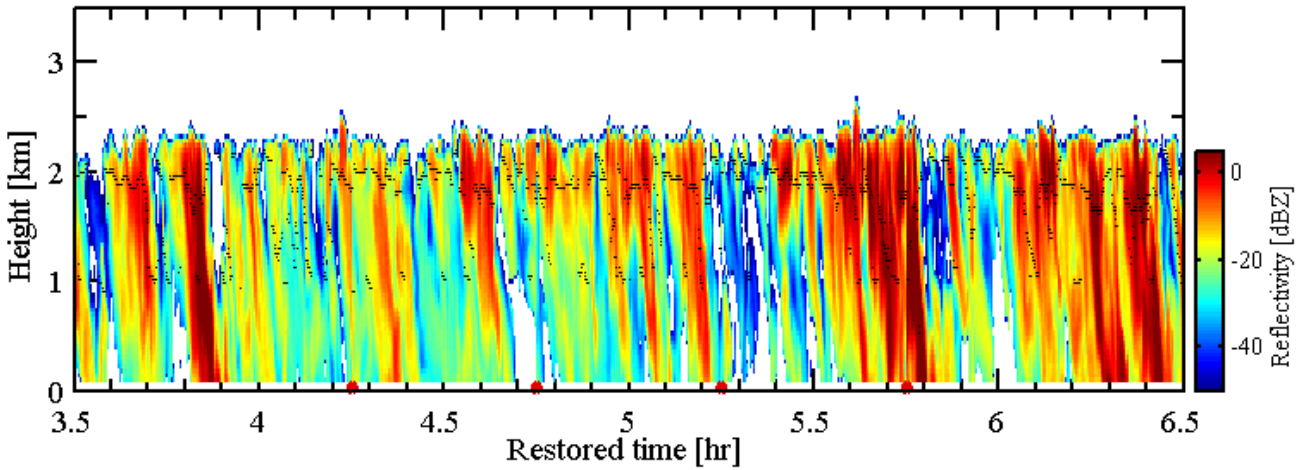


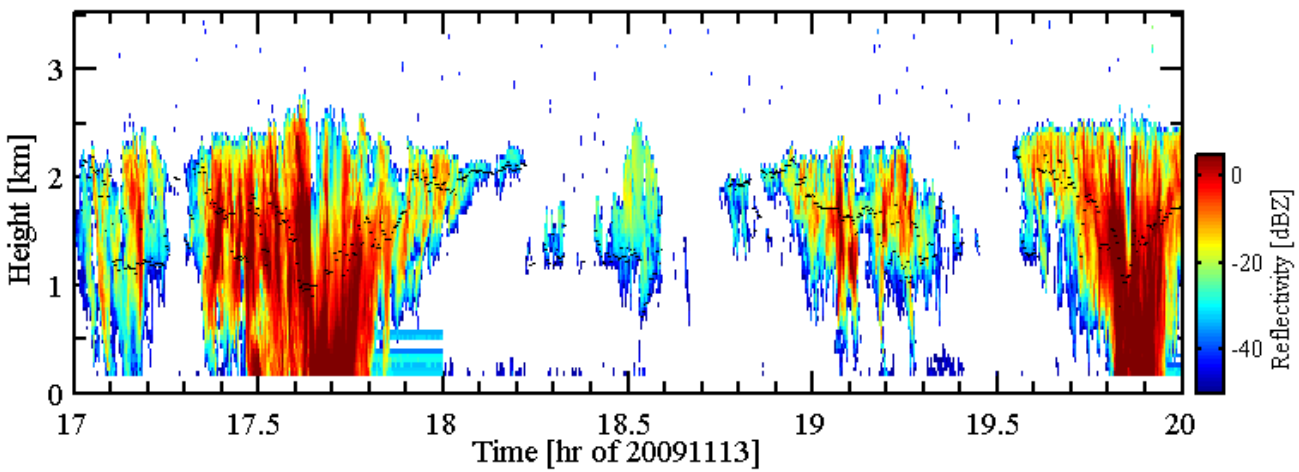
MODIS – 20km



3-hr stitched reflectivity curtain

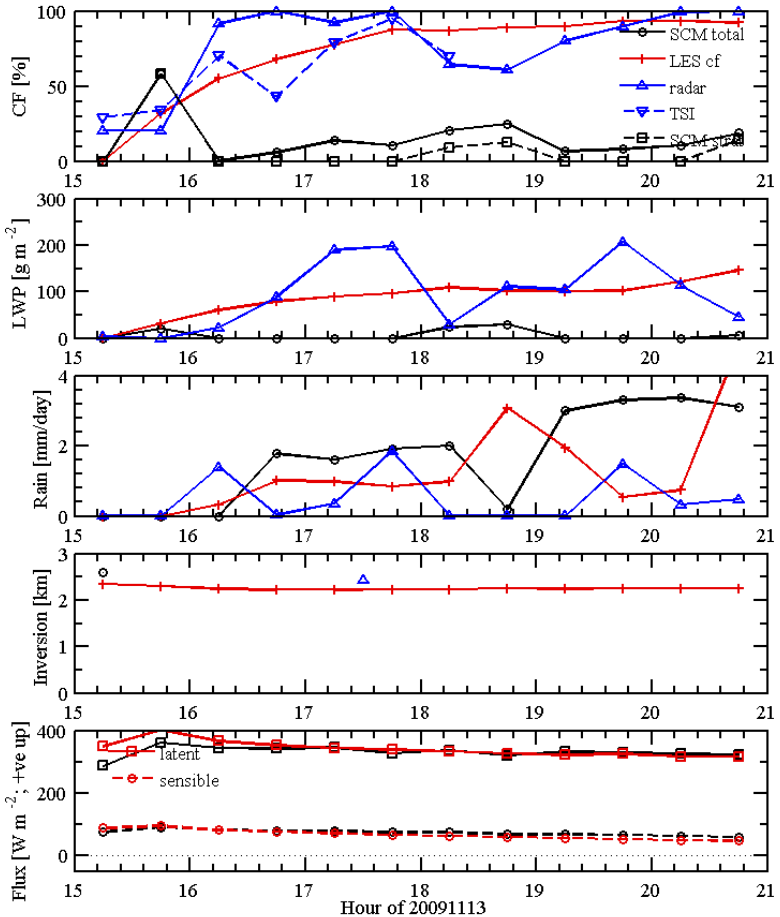


3-hr cloud radar reflectivity curtain

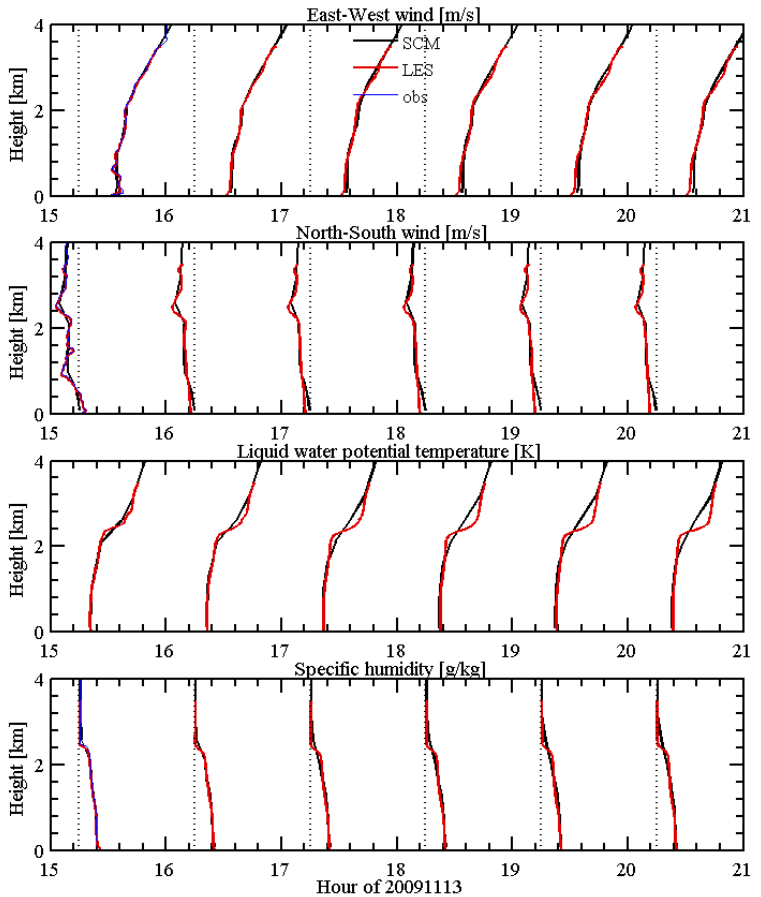


Single Column Model

Scalars



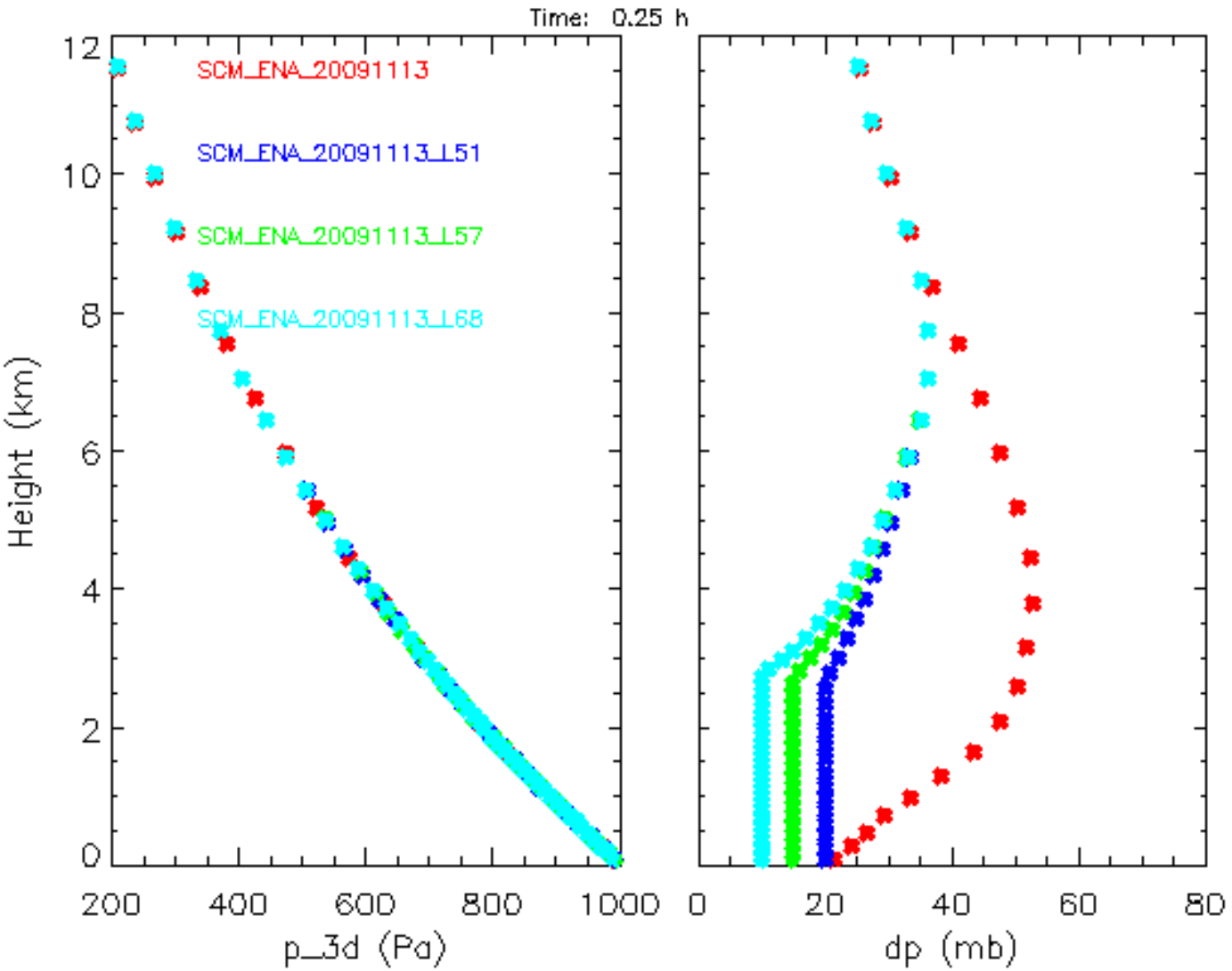
Soundings



Outline

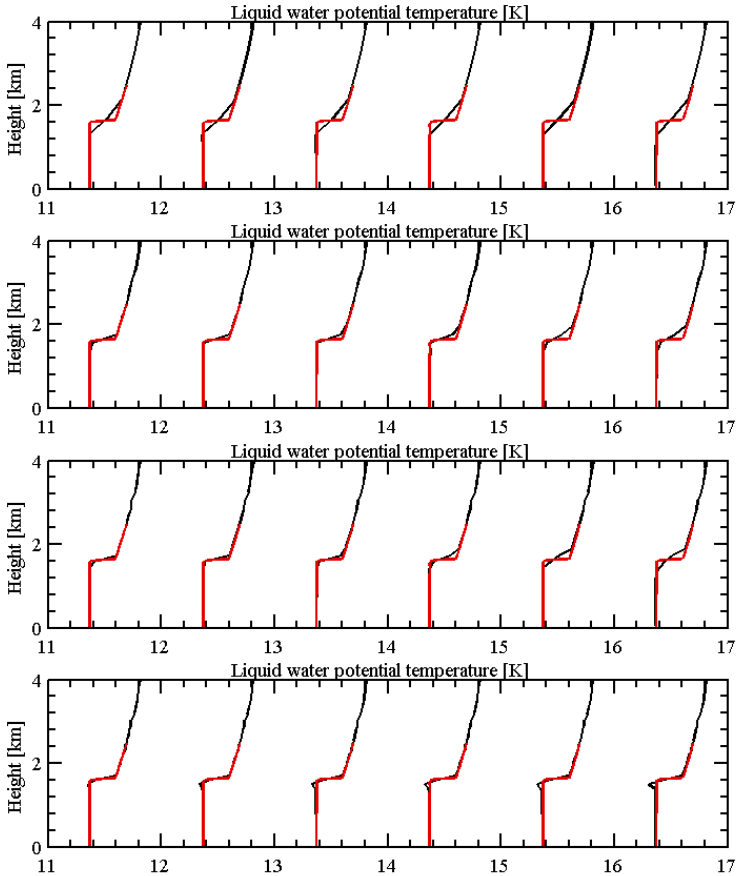
Increase the vertical resolution of the SCM

To better capture the inversion topping the boundary layer



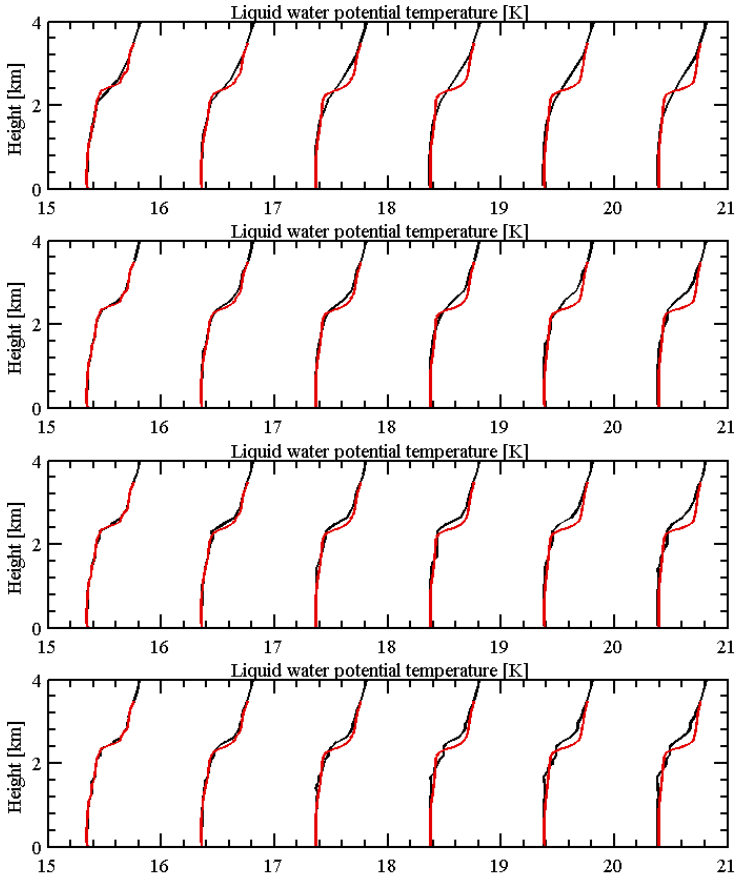
High-resolution SCM – Inversion

Stratocumulus case



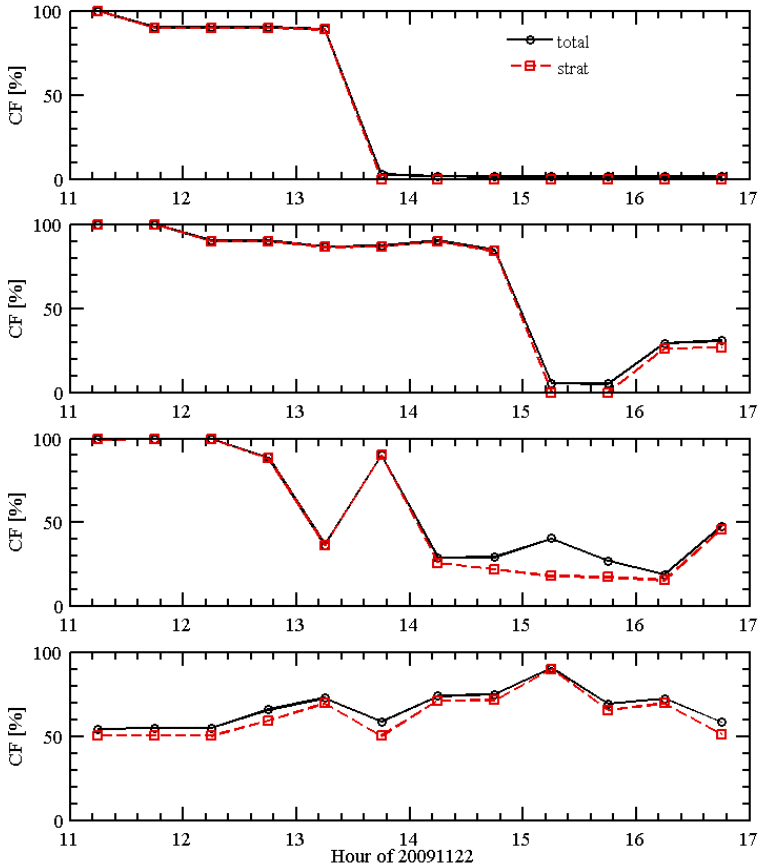
L40 L51 L57 L68

Shallow cumulus case



High-resolution SCM – Cloud fraction

Stratocumulus case



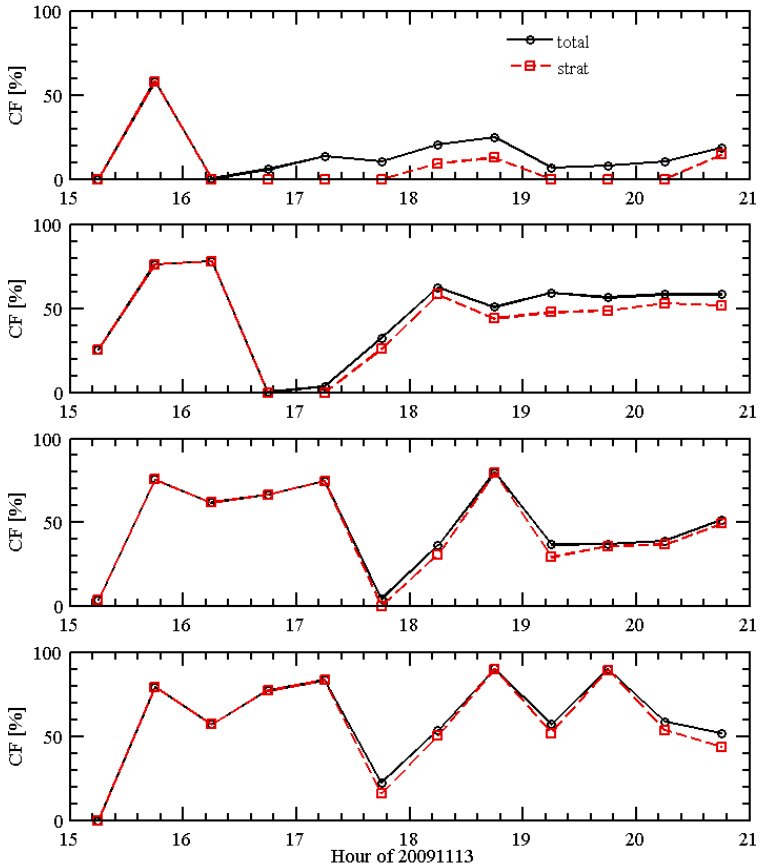
Shallow cumulus case

L40

L51

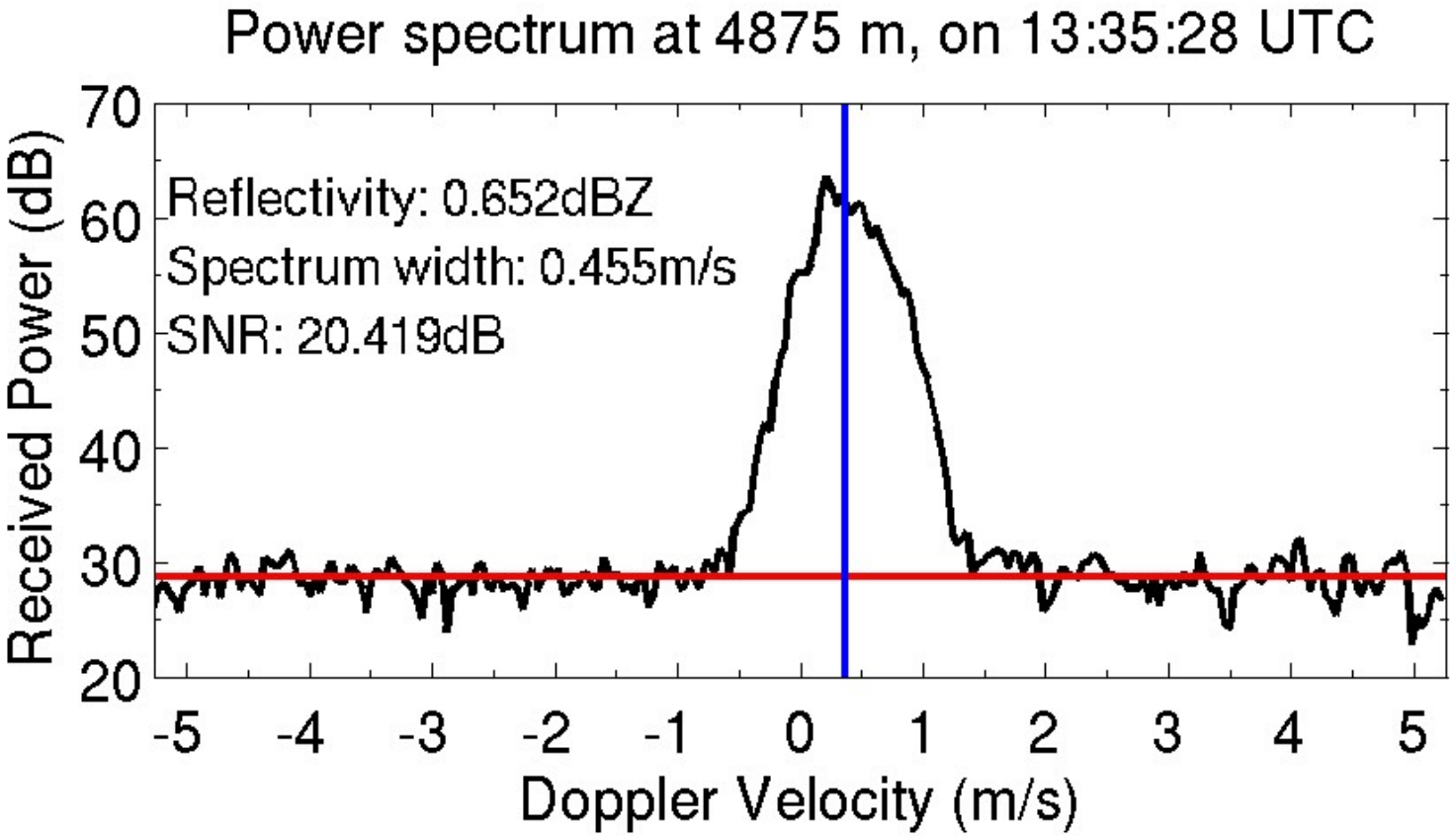
L57

L68



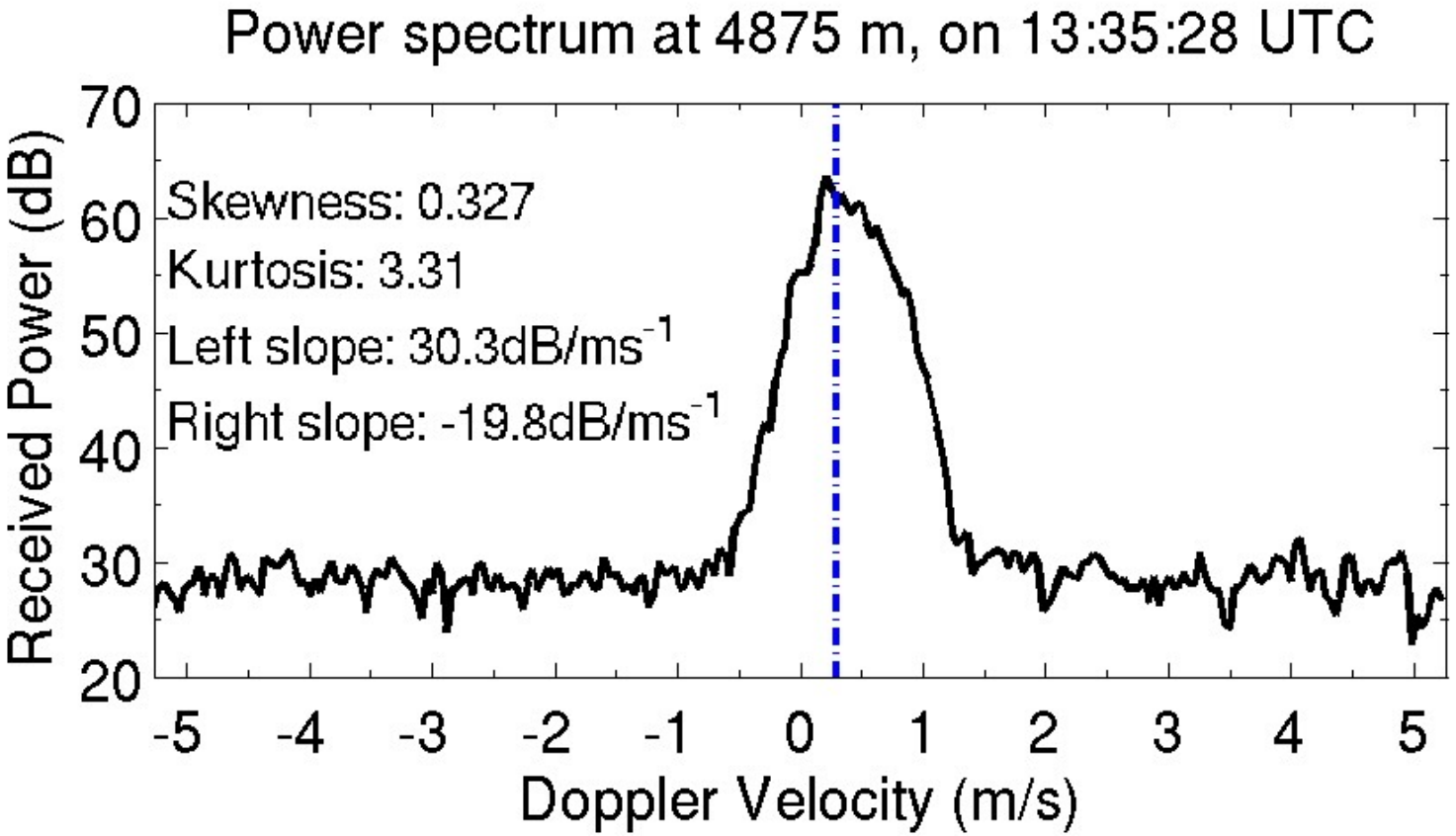
Analysis of cloud radar Doppler spectra and their moments

What are Doppler spectra?



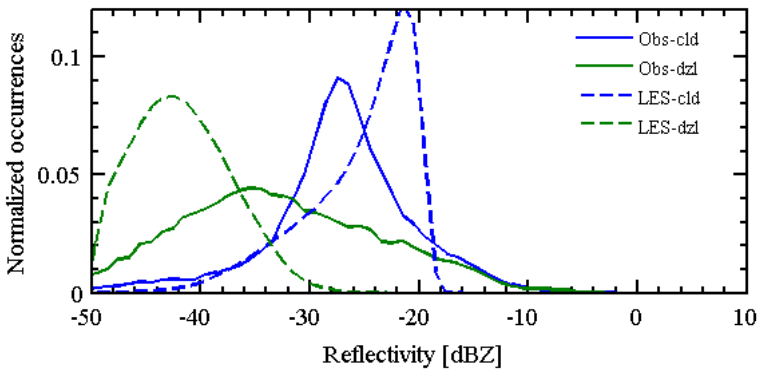
Analysis of cloud radar Doppler spectra and their moments

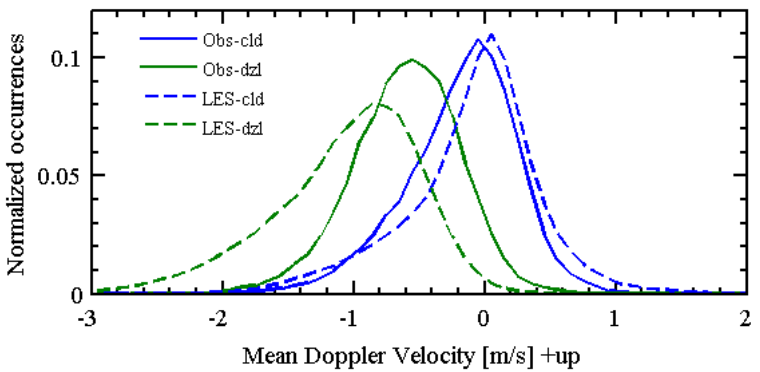
What are Doppler spectra?

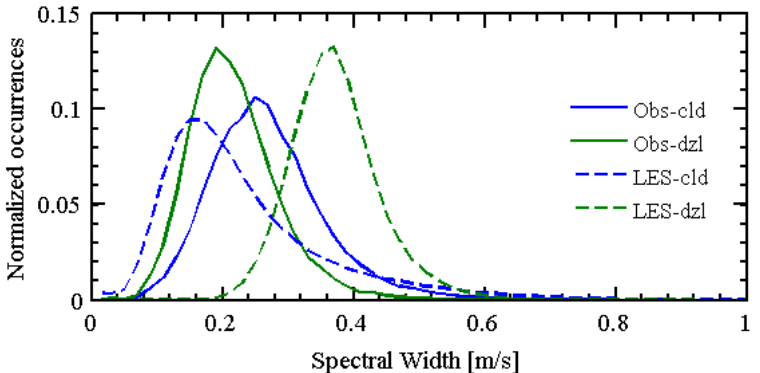


Distribution of standard moments

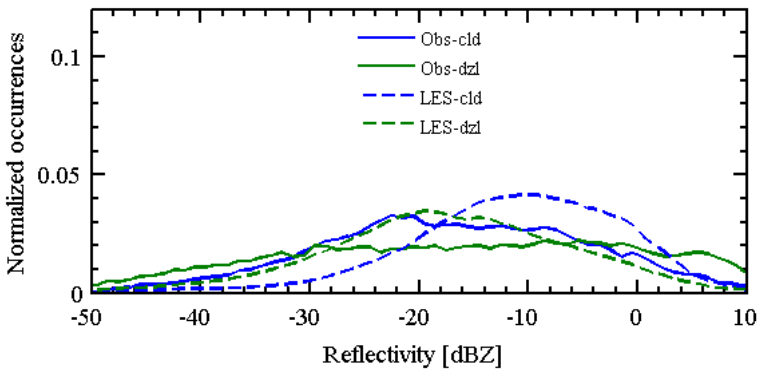
Stratocumulus case

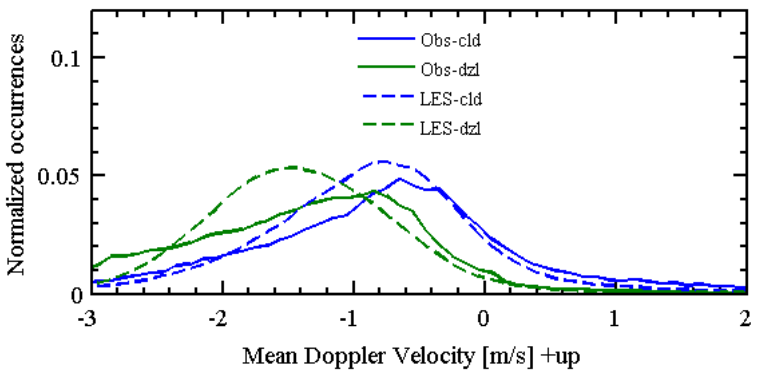


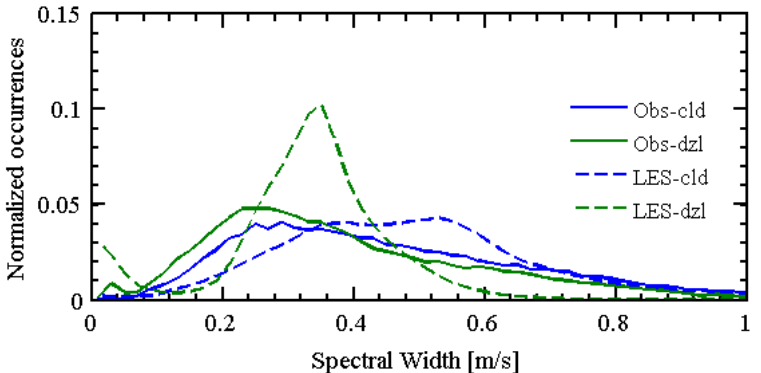




Shallow cumulus case

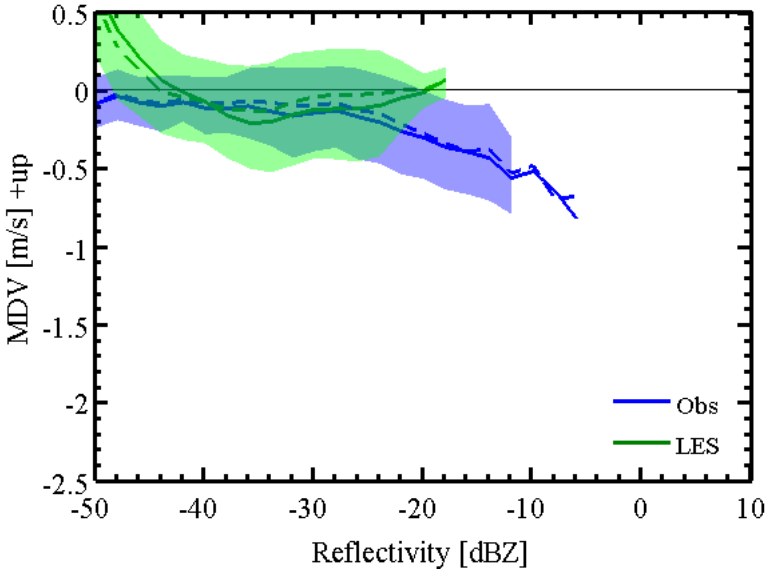


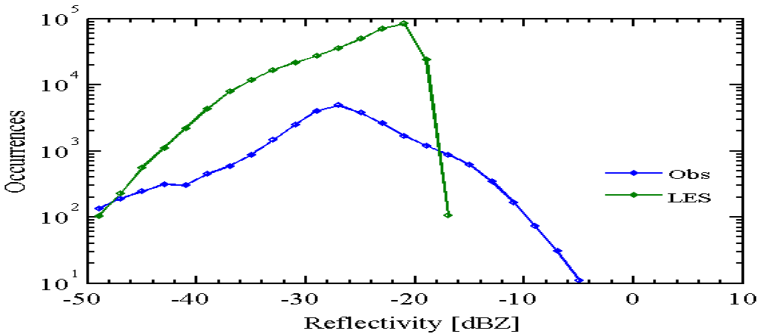




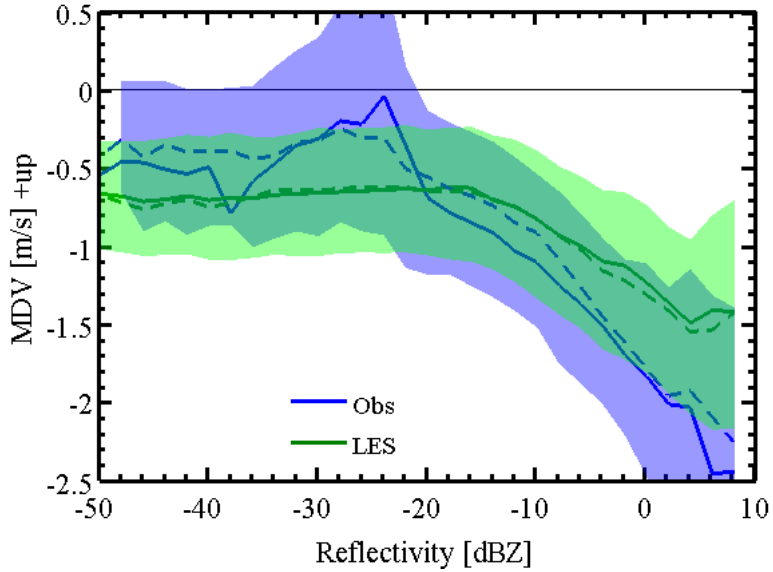
Relationship between *reflectivity* and *mean Doppler velocity*

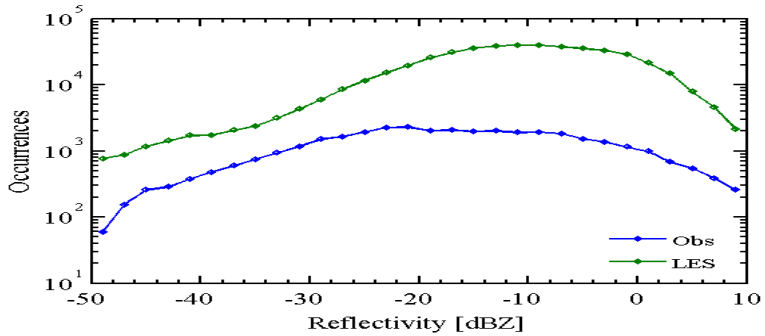
Stratocumulus case





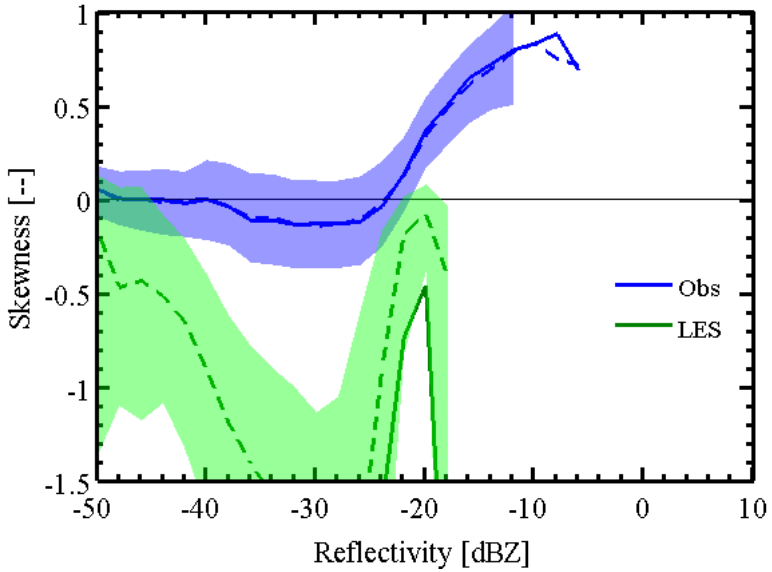
Shallow cumulus case

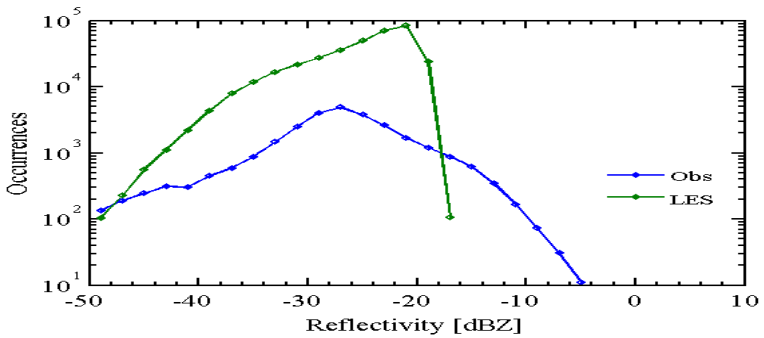




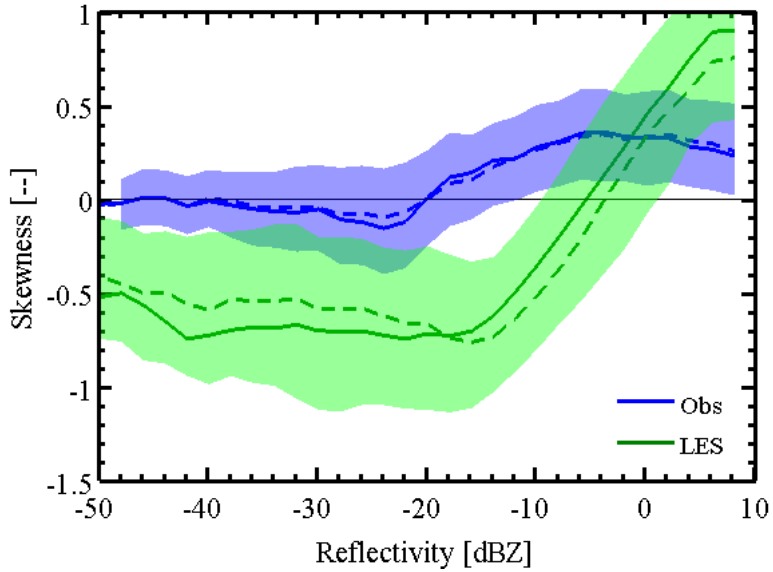
Relationship between *reflectivity* and *skewness*

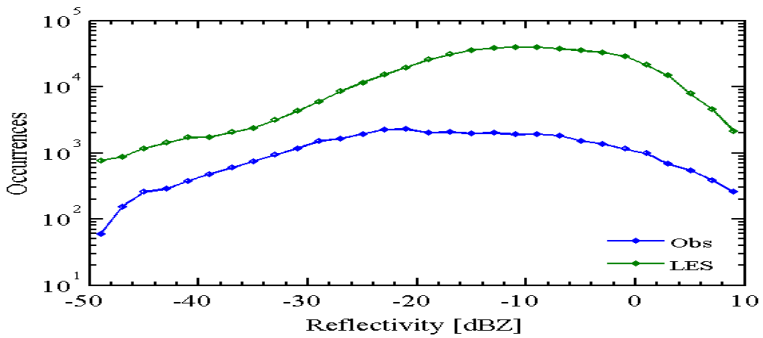
Stratocumulus case

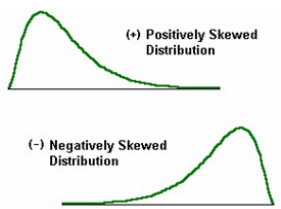




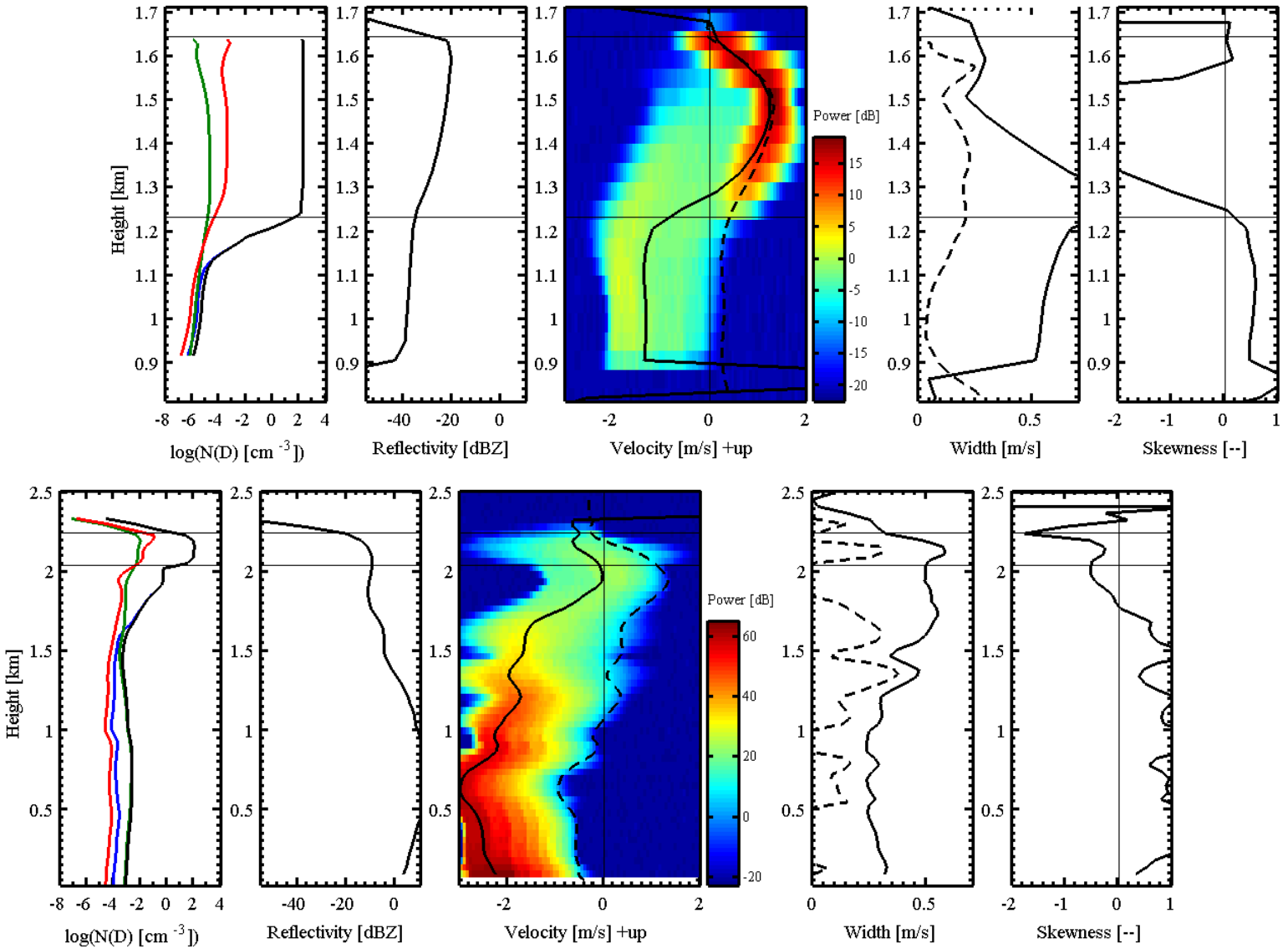
Shallow cumulus case







Spectrogram views



Summary

- The Azores are an interesting region to study clouds, especially in the boundary layer.
  - WS analysis shows the region to be a good lab to study major deficiencies in GISS GCM cloud property simulations.
  - ARM is deploying a permanent research facility there: the Eastern North Atlantic (ENA) site.
- We identified 2 opposite low cloud periods where GCMs struggle, and we are simulating them with the DHARMA LES and the GISS GCM.
  - Stratocumulus $\rightarrow$ dominated by the Azores high-pressure system
  - Shallow cumulus $\rightarrow$ cold-air outbreak behind a cold frontal passage
  - The LES captures well the difference in the horizontal structure of those cases, but requires improvement in the simulation of the cloud microphysical properties.
  - The SCM at native vertical resolution fails to simulate the shallow cumulus case and to maintain the stratocumulus coverage. Increasing the vertical resolution in the boundary layer helps in the representation of the cloud amount in both cases, but still includes severe errors in the simulation of cloud microphysical properties.

Future plans

- Further tests are underway
  - to examine the sensitivity of both the LES and SCM results to changes in the parameterization of cloud microphysical properties
  - to test the effects of any positive changes to the global cloud field
- Tools are in place to allow us to slide back and forth between global and local scale observations and model simulations.
  - Use SCM and LES case studies constrained by AMF observations to understand model deficiencies in simulating cloud processes and attribute them to forcing field inadequacies or parameterization problems.
  - Then, use the satellite and GCM analysis to understand the relevance of those deficiencies to the global model climate simulations.